ON THE INSTABILITY OF THE RAILWAY VEHICLES

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Abstract. The railway vehicles have two sources of instability. The most common is the hunting induced by the reversed conic shape of the rolling surfaces of the wheels. The other one is related by the anomalous Doppler effect that can occurs when the train velocity exceeds the phase velocity of the waves induced in the track structure. Some aspects regarding the two sources of instability are presented.

Keywords: railway vehicle, track, hunting, anomalous Doppler effect, limit cycle

1. Introducere

The railway vehicles experience two kind of instability behavior, one comes from the hunting and the other one is a consequence of the anomalous Doppler effect.

The hunting motion is induced by the reversed conic shape of the rolling surfaces. This motion is passed over to the bogie and to the vehicle body through suspension elements. During the traveling, the hunting is also sustained by track alignment irregularities; therefore, its intensity will be influenced by the amplitude of these irregularities. In addition, the regime of this motion depends on the running speed – at low speeds, the hunting is stable and at high speeds, it becomes unstable. The value of speed when the movement becomes unstable is known as the so-called hunting critical velocity. The cause of the unstable hunting is the creep forces between wheels and rails. The hunting stability and critical velocity were studied using linear models have been used in many papers. Sebeşan [1], Wickens [2], Joly [3] or Lee and Cheng [4] have investigated the influence of different parameters to create a basis for better bogie design. On the other hand, non-linear models were used by van Bommel [5], Pascal [6] and Mazilu [7] to investigate the main feature of the unstable hunting.

The vehicle instability caused by the anomalous Doppler effect is completely different. As already known, this phenomenon may occur when the train velocity exceeds the phase velocity of the waves induced by the train in the track structure. It is really dangerous because, when it begins, the level of vibration increases to such a high value that could affect the track structure and the derailment safety. This unsatisfactory phenomenon is signalled in the particular case of the lines crossing regions with soft soil (peat, organic clays or soft marine clays) [8, 9].

This paper presents some aspects regarding the two sources of instability that are met at the railway vehicles.

2. The hunting

The critical velocity of the hunting $V_l$ is obtained taking the hypothesis of the linear model – the linear critical speed. When the hunting motion of the vehicle becomes unstable, the oscillation is limited in amplitude by the wheel flanges and a limit cycle occurs. This behavior is influenced by the fact that the wheel and rail are in bi-contact (fig. 1). To point out the features of the unstable hunting, we consider the case of a bogie traveling on a sinusoidal local defect. For the numerical simulation, the parameters of the Y32 bogie have been considered, and a critical velocity of $V_l = 69.6$ m/s has been obtained.
Figure 2 shows the lateral displacement of the first wheelset for $V_l = 66.22$ m/s, defect amplitude: $u = 1.9$ mm and defect wavelength $\lambda = 18$ m. The movement is damped and the hunting of the bogie is stable. Fig. 3 presents the lateral displacement of the first axle for $V = 66.22$ m/s, defect amplitude: 2 mm (more precisely, 1.9985 mm) and defect wavelength of 18 m. The movement has a constant amplitude of 6.63 mm and a frequency of 4.34 Hz. The trajectories in plane of the phase are closed curves - limit cycle. The axles do not touch the interior flange of the rail.

If the defect amplitude increases to 2.1 mm, the movement amplitude increases along in time (see fig. 4). As a conclusion, the previous limit cycle (without touching the interior flange of the rail) is unstable. On the other hand, the amplitude of the hunting movement increases until the wheels reach contact with the interior rail flange. The movement becomes again periodic and the phase trajectories are closed curves – another limit cycle was reached. The amplitude of this limit cycle is 8.2 mm for the first axle, and the frequency is 4.82 Hz.
When the wheel flange hits the rail, wheel/rail bi-contact occurs and the rolling surface is unloaded and the flange becomes loaded, increasing the risk of derailment. Fig. 5 displays this interesting aspect for the leading axle. Practically, the wheel/rail bi-contact occurs during a period of 27 ms. The normal force on wheel flange has a maximum value of 38.7 kN. Meanwhile, the normal force on the rolling surface decreases for short time from 64.3 kN to 41.0 kN.

Figure 6 presents the Hopf diagram, the amplitude of limit cycle, either stable or unstable, versus the speed. The bogie hunting has two equilibrium solutions that depend on the value of the speed. For a bogie speed below $V_{nl} = 61.5$ m/s a solution without oscillation is the only existing equilibrium solution. For any initial excitation, the motion will be damped out. Certainly, this sentence remains true if no derailment occurs due to the extremely initial excitation. The speed $V_{nl}$ is the non-linear critical speed.

In the speed range $V_{nl} < V < V_l$, there are two stable solutions and one unstable solution. The stable solutions are the equilibrium position and the limit cycle caused by the wheel/rail bi-contact. The unstable solution is the limit cycle without touching the interior rail flange. The existence of this unstable limit cycle shows that the hunting instability may occur even at speeds below the critical hunting speed $V_l$ (linear model). The vehicle top speed must be small enough in order to avoid instability debut on accepted geometrical irregularities. In the speed range $V_l < V < V_d = 77$ m/s there is one stable solution, the limit cycle due to the bi-contact. For a bogie speed above $V_d$, the rolling surface is completely unloaded when the wheel smashes the rail and the derailment occurs.

2. Instability due to the anomalous Doppler effect

Considering the case of a force moving along an infinite homogenous elastic structure, the response of the structure at the moving point may be reflected by the equivalent dynamic stiffness. This stiffness depends on the frequency and the force velocity and it is represented by a complex number. The equivalent dynamic stiffness offers details regarding the structure dynamic features. Basically, the mechanical model of the structure at the moving point may
be reduced to one that includes only the concentrated elements (rigid mass, spring and dashpot), according to the sign of the real and imaginary parts of the equivalent dynamic stiffness. There has to be mentioned the possibility of appearance of the ‘negative viscosity’ when the imaginary part takes a negative sign - this possibility is related to the generation of anomalous Doppler waves in the structure. These waves are radiated by a moving object when its velocity exceeds the smallest phase velocity of the radiated waves, and they may generate the unstable vibration of the moving object.

In fact, the explanation of the vibration instability of an object moving along an elastic infinite structure was given by Metrikine [10], who demonstrated that the anomalous Doppler waves increase the energy of the transversal oscillation. The radiation of the anomalous Doppler waves is the only prerequisite for the instability, but not the sufficient one, as the instability is the result of the interaction between the moving object and the elastic structure.

The issue of the unstable response of different kinds of moving sub-systems and elastic structures modelling the railway vehicle/track system has been studied in many papers [11, 12]. The main goal of all these studies is to identify the instability regions in the parameters’ space of the systems considered using the so-called D-decomposition method. However, the dynamic behaviour of the unstable motion, when the sub-system velocity is higher than the critical velocity has not been investigated yet. There are two exceptions, our papers, one of them already published in Journal of Sound and Vibration [13] and other one accepted for publication in the Nonlinear Dynamics [14].

We have considered [14] the case of an oscillator moving along a Timoshenko beam on viscoelastic foundation (fig. 7). This model may be considered as one of the simplest ones for a railway vehicle moving along a tangent track and it may serve to point out the basic features of the stability loss phenomenon, from the qualitative point of view. We have demonstrated that the stability map has two stable regions and two unstable regions (fig. 8).

![Fig. 7. The uniform motion of an oscillator along a viscoelastic supported Timoshenko beam: (1) oscillator (M₁ = wheel, M₂ = bogie, M₃ = car body); (2) wheel/rail; (3) Timoshenko beam – the rail; (4) extra mass – sleepers and ballast; and (5) viscoelastic foundation – subgrade.](image)

![Fig. 8. Stability map.](image)
When the oscillator motion along the beam becomes unstable, the dynamic behaviour has two distinct parts: the transitory period and the steady-state period, as seen in Figure 9, where the contact force is presented for the speed of 100 m/s (within the first unstable region). At the beginning of the transitory period, the wheel and the rail are in permanent contact (the contact force is strictly positive), but the amplitudes continuously increase. The vibration frequency is about 7.3 Hz. In the end, the contact loss occurs – this aspect is signalled by the zero values of the contact force - and the dynamic regime is characterised by an exponentially high amplification and the highest magnitudes are registered. Finally, the motion stabilises at lower amplitudes and it shows as a periodic one – the steady-state behaviour.

Fig. 9. Contact force at 100 m/s.

A detailed time history of this regime can be seen in Figure 10. Note that the positive sense means the upward motion, while the negative one indicates the downward motion, according to the directness of the reference frame. The motion of the moving oscillator/beam system is generated by the action of two contrary factors: the anomalous Doppler waves pushing up the wheel mass and the static load that pushes it downwards. The system vibration is a limit cycle and its frequency is 7 Hz, a value lower than the one in the transitory behaviour, when the wheel and the rail are in a permanent contact. This aspect may be explained by the wheel motion, which is slower while the wheel is flying. The bogie has the highest amplitude. During the impact between the wheel and the rail, the contact force has a very high peak (about 1332 kN) compared to the static load.

Fig. 10. Limit cycle at 100m/s: (a) displacements, ———, beam displacement at the contact point; ——, wheel mass displacement; ——, bogie displacement; and —, car body displacement; and (b) contact force.

4. Conclusions

The railway vehicles have two sources of instability. The most common is the hunting induced by the reversed conic shape of the rolling surfaces of the wheels. The other one is related by the anomalous Doppler effect that can occurs when the train velocity exceeds the phase velocity of the waves induced in the track structure.
The hunting movement of the railway vehicles is caused mainly by the conic wheel profiles and limits the top speed due to its instability. The hunting has two limit cycles: an unstable mono-contact limit cycle and a locally stable bi-contact limit cycle. This last limit cycle is characterized by high accelerations and shocks. The Hopf bifurcation diagram shows that the critical speed (linear) is located between the non-linear critical speed and the derailment speed.

The vehicle instability due to the anomalous Doppler effect takes the shape of a limit cycle. This is the result of the action of the anomalous Doppler waves that force the low mass of the oscillator to take off and the static load that pushes the low mass downwards. In this way, the limit cycle takes the form of successive shocks.

References

THE CAM SYNTHESIS AND DIMENSIONALLY OPTIMISATION OF A VALVE TIMING MECHANISM WITH CONTINUOUS VALVE LIFT

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Abstract: An innovating solution for throttle-free load control for spark-ignition engines is variable valve timing system. In this paper is presented a cam synthesis and optimization, using the analytic method, of the valve timing mechanism with three elements and continuous valve lift variation. It is also presented the numerical algorithm for the mechanism’s synthesis and dimensionally optimization.

Key words: petrol engine, variable valve timing, continuous valve lift, cam synthesis, mechanism optimization

1. Introduction

For the traditional spark-ignition engines the timing configuration represents a compromise which does not allow the best engine performance to be achieved for all regime and load. Infinitely variable inlet valve lift and timing is used to control engine load, reducing throttling losses and fuel consumption [7]. It also improves low-end torque and transient response.

Variable valve timing (VVT System, or VVA - Variable valve actuation System) technology allows better engine performance by reducing fuel consumption and therefore low emissions, higher efficiency, highly precise responsiveness of the powertrain [5].

The key parameter for petrol engine combustion, and therefore efficiency, emissions and fuel consumption, is the quantity and characteristics of the fresh air charge in the cylinders. In conventional petrol engines, the throttle-based air control wastes about 10% of the input energy in pumping the air [6]. VVT systems with continuous valve lift variation, usually combined with cam phasers, are designed to eliminate the classical throttle and it’s inconvenient.

2. The proposed mechanism

The mechanism (Figure 1) [1] comprise the housing (9), the intake cam (1), the rocker arm (2), the hydraulic lash adjuster (3), the valve spring (4), the intake valve (5), the link element (6), valve lift control gear (7), intermediary rocker arm (8). The valve’s motion is provided from intake cam (1) via the rocker arm (2) which is hinged connected with the intermediary rocker arm (8). The link element (6) and intermediary rocker arm (8) are contact jointed, the contact surface being composed from two tangent circles R, R’ (Figure 2). The valve lift is controlled by the link element’s position, which is controlled with gear 7. Maximum valve lift (α has a maximum value) is achieved when the joint contact C2 coincides with the tangency point between circles R, R’ and the joint contact C1 is between circles r2, r1. Therefore, when the cam performs a complete rotation, C2 is only on the R’ circle. Intermediate valve lift is obtained by decreasing angle α, and C2 runs both on R and R’. No valve lift is obtained when the C2 contact runs only on R circle.
The mechanism’s mobility is unique, as it results from:

\[ M_3 = 3 \cdot n - 2 \cdot C_5 - C_4 = 3 \cdot 3 - 2 \cdot 3 - 2 = 1. \] (1)

3. Cam synthesis with analytic method

In [4] is presented the complete analysis of the mechanism’s motion.

It is considered the case presented in Fig. 2, in which the point \( O \) is simultaneously the center of rotation of adjustment element and the origin of general reference system \( OXY \). The general reference system is positioned so that the \( OX \) axis coincides with the \( O_3O \) segment and the value of \( A\hat{O}_2O_3^* \) angle equals to \( \pi / 2 \). The following notations are used: \( (X_1, Y_1) \) the \( O_1 \) point coordinates, \( r_1 \) the radius of cam base circle, \( R', R, r_2, r_d \), the circles radii point-centered respectively in \( O_6, O, O_2, A \), the distances \( d_1, d_2, d_3, d_5, d_6 \), respectively for \( O_2A, O_2O_3^*, O_3O_5^*, O_3B, O_3O_5 \), the angle \( \varphi_0 \) between the \( O_1O_2 \) axis and the \( OX \) axis, the adjustment angle \( \alpha \), the angle \( \theta_0 \) between the \( O_2O_3^* \) axis and the \( O_0X \) axis at the initial position.

The obtained equations which govern the movement of the mechanism are the following:

\[ X_2 - r_2 \cos(\theta + \theta_0 - \xi_2) - x_1 \cos(\varphi - \varphi_0) + y_1 \sin(\varphi - \varphi_0) - X_1 = 0 \] (2)

\[ Y_2 + r_2 \sin(\theta + \theta_0 - \xi_2) - x_1 \sin(\varphi - \varphi_0) - y_1 \cos(\varphi - \varphi_0) - Y_1 = 0 \] (3)

\[ x_{1p} \cos(\varphi - \varphi_0 + \theta + \theta_0 - \xi_2) - y_{1p} \sin(\varphi - \varphi_0 + \theta + \theta_0 - \xi_2) = 0 \] (4)

\[ X_2 - r_3 \cos(\theta + \theta_0 + \xi_3) + d_1 \sin(\theta + \theta_0) - X_1 = 0 \] (5)

\[ Y_2 + r_3 \sin(\theta + \theta_0 + \xi_3) + d_1 \cos(\theta + \theta_0) - Y_1 = 0 \] (6)

\[ X_p \cos(\theta + \theta_0 + \xi_3) - Y_p \sin(\theta + \theta_0 + \xi_3) = 0 \] (7)

\[ X_2 + d_2 \cos(\theta + \theta_0) - d_3 \cos \psi - X_3 = 0 \] (8)

\[ Y_2 - d_2 \sin(\theta + \theta_0) + d_3 \sin \psi - Y_3 = 0 \] (9)
where

\[ x_1 = \frac{\partial x_i}{\partial x_i}, \quad y_1 = \frac{\partial y_i}{\partial x_i}, \quad (10) \]

\[ X = \begin{cases} R \cos(\eta + \alpha), & \text{if } \eta \geq 0 \\ (R - R') \cos \alpha + R' \cos(\eta + \alpha), & \text{if } \eta < 0 \end{cases} \]

\[ Y = \begin{cases} R \sin(\eta + \alpha), & \text{if } \eta \geq 0 \\ (R - R') \sin \alpha + R' \sin(\eta + \alpha), & \text{if } \eta < 0 \end{cases} \quad (11) \]

\[ X = \begin{cases} -R \sin(\eta + \alpha), & \text{if } \eta \geq 0 \\ -R' \sin(\eta + \alpha), & \text{if } \eta < 0 \end{cases}; \quad Y = \begin{cases} -R \cos(\eta + \alpha), & \text{if } \eta \geq 0 \\ -R' \cos(\eta + \alpha), & \text{if } \eta < 0 \end{cases}. \]

Solving the equations (2), …, (9), for \( \varphi = 1 + 360^\circ \) using the numerical method Newton-Raphson, in which the unknown values are: \( X_2, Y_2, \xi_1, \xi_2, \eta, \theta, \psi \), it results the mechanism motion, defined by the parameters above mentioned.

The function which define the rocker arm’s movement law is

\[ \psi(\varphi) = \sin^{-1} \left( \frac{x + d_0 \sin \psi_0}{d_0} - \psi_0 \right) \quad (12) \]

and from relations (2), …, (9) results, using Newton-Raphson numerical method, the functions \( X_2(\varphi), Y_2(\varphi), \xi_1(\varphi), \xi_2(\varphi), \xi_3(\varphi), \eta(\varphi), \theta(\varphi), \psi(\varphi) \).

Next, from the equations (2), (3) are obtained the equations of circles envelope which depends by parameters \( \varphi, \xi_2 \)

\[ x_1 = (X_2 - X_1) \cos(\varphi - \varphi_0) + (Y_2 - Y_1) \sin(\varphi - \varphi_0) - r_2 \cos(\varphi + \theta - \xi_2 + \theta_0 - \varphi_0) \]

\[ y_1 = -(X_2 - X_1) \sin(\varphi - \varphi_0) + (Y_2 - Y_1) \cos(\varphi - \varphi_0) + r_2 \sin(\varphi + \theta - \xi_2 + \theta_0 - \varphi_0) \quad (13) \]

which comply the condition, [3]:

\[ \frac{\partial x_i}{\partial \varphi} \frac{\partial x_i}{\partial \xi_2} = \frac{\partial y_i}{\partial \varphi} \frac{\partial y_i}{\partial \xi_2} = 0 \quad (14) \]

wherefrom it results

\[ \tan(\xi_2 - \theta - \theta_0) = \frac{Y_2 - Y_1 + X_2 - X_1 - Y_2}{X_2 - X_1 - Y_2} \quad (15) \]

where \( X_2, Y_2 \) are the derivatives of \( X_2, Y_2 \) coordinates with respect to cam rotation angle \( \varphi \). Equations (13) which respect the condition (15) represent the cam synthesis expressed in its reference system \( O_x, x_1, y_1 \).

### 4. The mechanism dimensionally optimization

The approached optimization objectives are: the value of cam radius of curvature (geometric design parameter), the maximum and minimum valve lift which mechanism must assure (operation parameters).
In a cam synthesis problem the elements dimensions are chosen respecting the constructive and functionality constraints, and after that a cam synthesis proceeds, using a particularly valve lift law, \( s = s(\phi) \). As a result the maximum valve lift objective is always fulfilled, assuming that the cam profile is technically correct, i.e. it has no loops and the contact with the next element is permanently assured. The minimum valve lift is achieved by changing the mechanism adjustment angle, in this case the \( \alpha \) angle, so the valve lift can reach the needed height. Because the studied mechanism is a lost motion variable valve lift mechanism, it can perform zero valve lift by decreasing the adjustment angle in such a way that the \( C_2 \) contact point runs only on the \( R \) circle.

As regards the cam’s radius of curvature, we can achieve an optimum value by using an optimum contact curve on which the \( 2^C \) contact point evolves. As a result, the contact curve composed from circle arches \( R \) and \( R' \) must be redesigned. The optimum solution is to tangent insert a third circle arch, denoted with \( R'' \) and its length being \( |\hat{u}|R'' \), where \( \hat{u} \) represents an optimum angle. In this situation, the equations (11) become:

\[
X = \begin{cases} 
R \cos(\eta + \alpha), & \text{if } \eta \geq 0 \\
(R - R') \cos \alpha + R' \cos(\eta + \alpha), & \text{if } \eta \in (0;u); \\
(R - R') \cos \alpha - (R'' - R') \cos(\alpha - u) + R'' \cos(\eta + \alpha), & \text{if } \eta < u
\end{cases}
\]

\[
Y = \begin{cases} 
R \sin(\eta + \alpha), & \text{if } \eta \geq 0 \\
(R - R') \sin \alpha + R' \sin(\eta + \alpha), & \text{if } \eta \in (0;u); \\
(R - R') \sin \alpha - (R'' - R') \sin(\alpha - u) + R'' \sin(\eta + \alpha), & \text{if } \eta < u
\end{cases}
\]

Using the contact curve described above, the optimized design for the mechanism is represented in Figure 3, and \( T_1, T_2 \) are the tangency points between the three circle arches.

\[
X_p = \begin{cases} 
-R \sin(\eta + \alpha), & \text{if } \eta \geq 0 \\
-R' \sin(\eta + \alpha), & \text{if } \eta \in (0;u); \\
-R'' \sin(\eta + \alpha), & \text{if } \eta < u
\end{cases}
\]

5. Numerical example

Let us consider the following dimensions (mm, deg): \( O_1(-18;18), O_3(-20;0), r_1 = 10, r_2 = r_4 = 6, d_1 = 16, d_2 = 12, d_3 = 14, d_5 = 25, d_6 = 28, R = 26, R' = 11, R'' = 78, u = -35^\circ, \alpha = 35 + 53.1926^\circ, O_3O_5 = 42, O_0\hat{O}O_3 = 15^\circ. \)

Using the valve lift law presented in Fig. 6 for \( \alpha = 53.1926^\circ \) (with heavy line) it results the synthesis cam presented in Fig. 5.
In this case, the minimum radius of curvature is 5.01 millimeters (it was considered, as an optimization objective, a radius of curvature with a minimum value of 5 millimeters). In Fig. 4 is presented a standard synthesis cam which was obtained with a standard adjusting curve formed only with $R$ and $R'$ circle radius. The minimum radius of curvature is 0.07 millimeters, which, technically, represents a problem in mechanism’s proper operation.

By decreasing the adjustment angle $\alpha$ from 53.2 degrees down to 35 degrees results the valve lift family of laws, showed in Fig. 6.

As resulting from Fig. 3 the studied mechanism can achieve zero valve lift, which means that the mechanism can perform also the valve deactivation, and therefore, the cylinder deactivation.

This strategy is used mainly in multi-cylinder engines (with V6, V8 and V10 configuration), in order to perform the deactivation of some cylinders, which leads to an improved fuel economy.

![Fig. 4. Standard cam synthesis profile](image1)

![Fig. 5. Optimized cam synthesis profile](image2)
5. Conclusion
The kinematic analysis shows that the mechanism offer a continuous variation of the valve lift, with valve displacement starting from no lift to a maximum lift around 9 mm. Also the valve opening and closing points varies with the command angle $\alpha$. The synthesis and optimization procedures represent the first step in order to achieve an operational design for the mechanism. Also, allows to study the dynamics of the mechanism, resulting the final mechanism configuration.

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References
EVALUATION OF THE PIPELINES BY METHOD
FITNESS FOR SERVICE

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Abstract. Evaluation of the pipelines based on Fitness for Service method is a useful procedure in making a decision on repairing or maintaining pipelines running at its current or reduced parameters. The decision has important consequences for the charges to fix the pipeline and the risks associated with possible effects to the environment and safety of persons. The paper illustrates such an assessment at Level 1 and 2 for a defect type out of roundness.

Key words: fitness for service, out of roundness.

1. Introduction

Many of existing pipelines transport systems in Romania (liquid petroleum products or gas) are old, being in operation for 30-40 years. The replacing of these pipes raises many issues, including the financial ones, which are the most important [7, 9]. Due to the technical progress the operators of transport systems use automated detection systems (based on magnetic field or ultrasounds) Fig. 1 for the inspection of pipelines. These systems are sent through the pipeline, pushed by gases or liquids. The result of the evaluation provides a map of pipeline defects. The precision of tracking and identifying the type of defect is quite good. These operations are subject of activity of the inspection companies from the country or outside and they are quite expensive, an average price of 3-5 euro / m is common. Following these operations are identified critical defects that have to be rectified immediately.

Also, there are many defects that are not significant and are excluded from reporting. There is an intermediate category of defects that require a careful analysis, from which it can decide: whether the pipeline will be repaired; it can expect an estimated time to repair; using the pipeline at a reduced working pressure. In general the scanning defects of pipeline are classified using simple calculations based on the assessment of fault geometry: length, depth, width, average depth, position relative to other faults. These assessments are recognized as standards assessment level 1 [1, 3-5]. The desire of operators is to minimize pipeline interventions; especially given that much smaller quantities are transported (due to the economic crisis, the earnings are low). In general this is possible because they have a reserve capacity until it will reach critical conditions. More nuanced assessments, which are partially resolved by the use of procedures, computer programs, qualify for Level 2. At this level you have to know the detailed description of the defect (description around the...
minimum thickness) and to evaluate groups of defects, where the standards provide partial procedures. Another assessment, Level 3, based on modeling the defect region using finite element method is possible, being used with good results. This article will present an assessment taken at a geometric defect (type deviation from circularity), made by standard procedures from [1], levels one and two. Actual data used are subject to inspection by an intelligent device Pipeline Pigs (Pipeline Inspection Gauges) see [7].

2. Method of evaluation of defect at level 1

In such level of the assessment the defect is checked if there is a difference between the maximum inside diameter of the pipe $D_{max}$ and minimum $D_{min}$ (Fig. 2) according to relation (1):

$$D_{max} - D_{min} \leq 0.01D_{int}$$

(1)

To highlight the method, a numerical example accompanies the assessment procedure is introduced next to the appropriate relationship $339.87 - 328.98 = 10.89 \ mm \leq 3.28 \ mm$, false verification Level 1 is not satisfied. This case requires an evaluation of Level 2 or 3.

3. Method of evaluation of defect at level 2

Standard [1] includes the following steps to evaluate deviations from circularity at this level:

**Step 1:** determining the following variables necessary for assessing the deviation of circularity:
- $C_s$–factor to account for the severity of the out-of-roundness, $C_s=0.5$ use for a purely oval shape and $C_s=0.1$ for shapes which significantly deviate from an oval shape;
- $D_m$–average diameter of the pipe, $D_m = (D_o + D_{int})/2 = (340 + 324)/2 = 332 \ mm$;
- $D_o$–the outer diameter of the pipe and corrected with $LOSS$ and $FCA$ if possible $D_o= D_{int} + 2(t_{nom} - FCA - LOSS) = 324 + 2(13.5 - 0.5 - 0) = 340 \ mm$;
- $D_{max}$–maximum inside diameter of the pipe, $D_{max}=339.87 \ mm$;
- $D_{min}$–minimum internal diameter of the pipe, $D_{min}=328.98 \ mm$;
- $D_{int}$–the inside diameter of the pipe, $D_{int}=324 \ mm$;
- $E_y$–longitudinal modulus (Young's modulus), $E_y=205000 \ MPa$;
- $FCA$–corrosion accepted, $FCA=0.5 \ mm$;
- $t_{nom}$–corrected nominal thickness tolerance thick if possible, $t_{nom}=13.5 \ mm$;
- $t_{ul}$–uniform thickness of metal measured beyond the local defect;

**Fig. 2.** The characterization of global out of roundness.
$\nu$– Poisson’s Ratio, $\nu = 0.3$;

$L_f$– Lorentz factor, which measures the efforts of one side compared with those in a straight line; $L_f = 1$. If the pipeline contains local strain when it has a specific formula $L_f$ see [1] paragraph A.5.5.1. For the characteristics of deviations from circularity, the standard highlights two situations:

a) For global out of roundness, Fig. 2 is not the case for example analyzed in this article because we have a general loss of circularity.

b) For a general out of roundness (an arbitrary shape) Fig. 3, it is necessary a section through the pipeline, knowing radius at different angles (when the pipeline is not under pressure). The profile can be represented in polar coordinates, by radius function of current angle. This expression can be determinate by the representation in a Fourier series. This profile is obtained from the values of inspections (the inspection device Fig. 1) and it is show in Table 1.

**Fig. 3. The characterization of general of roundness.**

**Step 2:** it is determined the wall thickness used in the evaluation $t_c$.

$t_c = 13.5 - 0 - 0.5 = 13$ mm

**Step 3:** it is determined the circumferential tensions (from the theory of membrane), using the thickness calculated in step 2:

$$t_c = t_{nom} - LOSS - PCA$$  \hspace{1cm} (2)

$$t_c = 13,5 – 0 – 0,5 = 13 \text{ mm}$$

$$\sigma_m = \frac{E}{B} \left[ \frac{P}{A(t_c - MA)} - Y_{B31} \right]$$  \hspace{1cm} (3)

$E$– weld joint efficiency, if it is unknown then $E = 0.7$; it was considered $E = 0.9$

$P$– design internal pressure $P = 5.7$ MPa

$MA$– deviation of execution, $MA$ in the case of threaded components is the nominal thread depth, it was considered $MA = 0$.

$Y_{B31}$– coefficient which takes into account the standard B 31, used to determine the thickness of pipes, if $t_{min} < D_o / 6$ ($t_{min} = t_c = 13 \text{ mm} = 340 / 6 = 56.6 \text{ mm}$) and lower temperature of $492 \degree C$ (all types of materials) $Y_{B31}=0.4$. Characteristics of the material must be carefully assessed [6,8], for steel Grade X 60, we have:

$R_{\sigma, 0.5}$– yield stress at the assessment temperature: $R_{\sigma, 0.5} = 414 \text{ N/mm}^2$;

$R_m$– tensile strength: $R_m = 517 \text{ N/mm}^2$;

$A_{2in}$– percentage elongation after fracture: $A_{2in} = 24 \%$;
Fig. 4. The recording of general out of roundness of a real pipeline with a device with a magnetic field [7].

Table 1. The characterization of general out of roundness (Fig. 4)

<table>
<thead>
<tr>
<th>No.</th>
<th>Angle 0, sexagesimal degrees</th>
<th>Radius R, mm</th>
<th>No.</th>
<th>Angle 0, sexagesimal degrees</th>
<th>Radius R, mm</th>
</tr>
</thead>
<tbody>
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<td>144.6</td>
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</table>

$KV$ – resilience (breaking energy) at $0^\circ C$: $KV = 80 \ldots 100$ J;
$SA$ – allowable stress for the component at the assessment temperature based on the original construction code;
$c$ – safety coefficient for the material of the pipeline [8, 9], $c=1.4$

$SA = \frac{R_{\text{max}}}{c} = \frac{414}{1.4} = 297.71 \text{MPa}$
Step 4: It is determined factor for out of roundness (the ratio of tensions of the deformed pipeline and circumferential efforts from membrane theory), at the current angle $\Theta$, when $k_n$ and $D_e$ are coefficients calculated with expressions in (5) and (6):

\[ R_{5}^{pr} = \frac{6}{\text{c}} \sum_{n=2}^{N} A_n \cos(n\Theta) + B_n \sin(n\Theta) \]

(4)

\[ k_n = \frac{PR^2}{(R_i^2 - 1)D_c} \]

(5)

$R$–average radius of the cylinder, measured at halfway of the thickness, $R = D_m / 2 = 332 / 2 = 166$ mm.

\[ D_c = \frac{205000 \cdot 13^3}{12(1 - 0,3^2)} = 41244847 \text{N/mm} \]

The coefficients $A_n$, $B_n$ in equation (4) are the Fourier coefficients involved in the expression of $R_i$ radius (the point $i$ see Tab. 1) the profile inside the pipe:

\[ R_i = R_{m2} + \sum_{n=1}^{N} \left( A_n \cos \frac{2\pi i - 1}{N} n + B_n \sin \frac{2\pi i - 1}{N} n \right) \]

(7)

To determine these factors, the value $R_{5}^{pr}$ equation (4) and $RSF$ value equation (8), has developed a program (Matlab) using an algorithm presented in [9].

Step 5: It is determined remaining strength factor for a component $RSF$ with relation:

\[ RSF = \min \left[ \left( \frac{H_F \sigma_{FA}}{\sigma_m(1 + R_{b2}) + \sigma_{m2}(1 + R_{b2})} \right), 1 \right] \]

(8)

where $\sigma_m - \sigma_{m2}$ circumferential tension, $R_{b2} - \sigma_{m2}$ additional efforts in the section (it has not been calculated because $R_{b2} = -1$), $H_F$ the ratio of additional efforts of deformed pipe and circumferential tensions from membrane theory.

Chosen for the angle value calculation used in (4) according to Fig. 4 is $tetac = 285$ degrees (where there is a pronounced change in the profile), using the program we obtained $R_{5}^{pr} = -1,24$, $Rb = 1,24$, $RSF = \min(2,3)$; $1 = 1$ higher than allowable remaining strength factor $RSFa = 0,9$. In conclusion, the qualification of assessment at Level 2 is acceptable.
4. Conclusions

The evaluation of pipeline based on the method Fitness for Service is a useful method in making a decision on repairing or maintaining of pipeline running at current or reduced parameters [9]. The decision has important consequences for the charges to be or not to fix the pipe and the risks associated with the possible faults to the environment and safety of persons. Current assessment programs use Level 1 on the data-analysis during the inspection and the evaluation of data at Level 2 and 3 may be appealing to the companies that have as their object of investigation assessment of pipelines, but with additional costs. Engineers involved in this activity can run these assessments on the recommendations of the standards, but through the means of some software programs [10]. At a more advanced Level 3 analyze is useful in substantiating these decisions [7, 9].

References
SIMULATION AND MODELING OF CYCLOID GEARS USED IN ORIENTATION MECHANISM OF ROBOTS

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Ş.l. dr. ing. Adrian RUNCEANU - “Constantin Brâncuşi” University of Târgu Jiu, Engineering Faculty

Abstract: Cycloid reducers compared with classical reducers have low axial and radial gauge, high transmission ratio, and a better reliability. Cycloid gearing roller, through its qualities, has an important role in modern mechanical transmissions. The difference between numbers of teeth of the cycloid gear roller can be equal to 1 (|z1 - z2| ≥ 1), without risk of interference, as a result, can be obtained big gear ratios in accordance with in lower overall dimensions, while the classic gear have the difference between teeth number min |z1 - z2| ≥ 4. In this paper, the physical prototype of a new version of roller cycloid reducer is presented. Also one tries to test this variant of cycloid gear on a modern stand trial.

Keywords: Orientation Mechanism, Cycloid Gears, Experimental Testing, Gear Prototype.

1. INTRODUCTION

The characteristics of cycloid reducers are: compact structures, high exploiting safety and shock absorbing capacity, are less expensive, not noisy, long life functioning and high transmission ratio.

The most essential robot peripheral is the end-effector, or end-of-arm-tooling. Common examples of end effectors include welding devices (such as MIG-welding guns, spot-welders etc.), spray guns and also grinding and debarring devices (such as pneumatic disk or belt grinders, burrs etc.) and grippers (devices that can grasp an object, usually electromechanical or pneumatic). Another common means of picking up an object is by vacuum [9] and [10].

End effectors are frequently highly complex, made to match the handled product and often capable of picking up an array of products at one time. They may utilize various sensors to aid the robot system in locating, handling, and positioning products [6].

The design of robotic mechanisms is a complex process involving geometric, kinematic, dynamic, tolerance and stress analyses [5], [11] and [12].

In the design of a real system, the construction of a physical prototype is often considered. Regarding the orientation of the gears in the prototyping machine, it is advantageous to keep their axis vertical for smoothness of operation and strength [5].

The orientation mechanisms - OM of industrial robots have two or three output rotations. In the case of OM with cylindrical/conical gears, the kinematic chains are in correspondence with the known planetary mechanisms [12].

While the partially coupled orientation mechanisms with two rotations (OM-2R) are simple, those with three rotations (OM-3R) have a complex structure [7].

Reducing of the speed is a technical goal imposed by the need to adapt relatively high speeds of modern engines at the requirements of effectors which they serve.

2. PROTOTYPE CYCLOID REDUCER'S PRESENTATION

A new variant of cycloid reducer, equipped with a sun gear, which is proposed by the authors, is illustrated in Figure 1; this contains a cycloid gear pair with rollers, consisting of a
fix sun gear with internal cycloid teeth 3 and of more eccentric rollers 2. The element H (which contains an eccentric bearing) designates the reducer’s input, while the element 1 (on which the rollers 2 are eccentrically articulated) designates the output. In the premise that the reducer uses \( z_2 = 16 \) rollers (as teeth), then \( z_3 = z_2 + 1 = 17 \) teeth and, implicitly, the reducer accomplish the transmission ratio [1] and [2]:

\[
i_0 = i_{13}^H = \frac{\omega_{13}}{\omega_3} = i_{12}^H \cdot i_{23}^H = (1) \frac{z_3}{z_2} = \frac{17}{16} = +1,0625
\]

\[
i_{13}^H = \frac{\omega_{13}}{\omega_3} = \frac{\omega_{13} - \omega_3}{\omega_{13} - \omega_1} = \frac{1}{1-\frac{\omega_{13}}{\omega_3}} = \frac{1}{1-\left(\frac{17}{16}\right)} = -16 \tag{2}
\]

In the assumption of friction considering, the reducer efficiency \( \eta_{H1} \) can be theoretically established through the following relation:

\[
\eta_{H1} = \frac{-T_1 \cdot i_{13}^H}{T_H \cdot \omega_{H3}^H} = \frac{l - i_0}{l - i_0 \cdot \eta_0^w}
\]

where \( T_H \) and \( T_1 \) are the input and respectively output torque, \( \eta_0 \) is the reducer internal efficiency (\( \eta_0 = \eta_{H1} = \eta_{H2} = 0,990 \) and \( \eta_{H2} = 0,995 \)) and \( w \) is the efficiency coefficient \( (w = \pm 1) \) that models the power circulation in the fixed axis unit associated to the planetary unit[1, 2):

\[
w = \text{sgn}(\omega_{13} \cdot T_1) = \text{sgn}\left(\frac{\omega_{13} \cdot T_1}{\omega_{13} - \omega_3}ight) = \text{sgn}\left(\frac{\omega_{13} \cdot T_1}{\omega_{13} - \omega_3}ight) = \text{sgn}\left(\frac{l_0}{1 - i_0}ight) = \text{sgn}\left(\frac{17/16}{1 - (17/16)}\right) = -1 \tag{4}
\]

Fig. 1. The cycloid reducer equipped with eccentric rollers (2) and a sun gear (3)

3. EXPERIMENTAL TESTING

The experimental testing of cycloidal roller gear was performed on trial stand equipment located in the Transylvania University of Brasov.

The test stand comprises two synchronous machines Siemens, brushless, two Siemens converters, two torque and speed transducers, a tri-axial vibration transducer, a PC type computer system, external data acquisition equipment and a board for serial communication with engine controllers. After entering input data were drawn graphs that represent the torques recorded by transducers. In each graph, the top is illustrated the torque engine and in the bottom is the torque brake [13].
Based on Figure 2 were obtained the next collated results systematized in the Table 1, where TM1 and TF1 are average torques recorded by the transducer of electric-motor machine and the electric-brake machine, in the case of the decoupling of reducer’s input and output.

### Table 1

<table>
<thead>
<tr>
<th>Stand with decoupled gear’s input and output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brake average speed [rpm]</td>
</tr>
<tr>
<td>---------------------------</td>
</tr>
<tr>
<td>-24.87196937</td>
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<tr>
<td>-59.49240742</td>
</tr>
</tbody>
</table>

**Fig. 2.** The torques recorded by transducers, where input and output gear decoupling and coaching of electric - driver machine, with speed of 320 [rpm] and 960 [rpm], and electric - brake machine, with speed of 20 [rpm] and 60 [rpm]

**Fig. 3.** The torques recorded by transducers for: gear engaged, no-load brake and engine trained successively with speeds: a) 320 [rpm] and b) 960 [rpm]
In Figure 3 are shown the torques recorded by the transducer adjacent engine and, also, by the transducer adjacent brake for: gear engaged, no-load brake and engine trained successively with speeds: a) 320 [rpm] and b) 960 [rpm].

Near by, in Figure 4 are illustrated the torques recorded by transducers for: gear engaged, brake loaded sequentially to 32 Nm (a, c) and 40 Nm (b, d) and engine trained successively with speeds: 320 [rpm] (a, b) and 960 [rpm] (c, d).

After processing data from Figure 3 and 4, one obtained some results collated in Tables 2 and, respectively, 3.

In Table 2.a. are systematized the average values for engine speeds (nM2) and brake (nF2), and, also, for the torques recorded by the transducer adjacent to the engine (TM2) and at the adjacent brake (TF2), in the case in which the motor-gear-brake system works with no load brake (idling on the brake).

In the next Table 2.b., based on results from Tables 1 and 2, a. have been set the average resistant torques of the gear, proper to the dry running of brake (TF3=TF2+TF1) and residual torque engine of gearbox (TM3=TM2-TF3/i/η).
Residual engine torque of the reducer represent, according to the calculation expression: 
\[ TM3 = TM2 - TF3 / \eta \], the needed torque to drive the gearbox without load (no load to his riding).

For compatibility with common theoretical assumptions, the residual engine torque will be excluded from the calculation of efficiency; in this way, it becomes possible direct comparison between the theoretical value of the yield and its values based on experimental data processing.

On the basis specified in Table 3 were systematized, with the previous tables, the averages values of speeds and torques calculation of yield and, also, the values obtained for the gearbox’s yield during the tested regimes.

With calculus, the theoretical yield was obtained for the considered reducer:

\[ \eta = (1-i_o)/(1-i_o/\eta_0) = (1-1,0625)/(1-1,0625/0,99) = 0,8534 => \eta = 85,34\% \quad (5) \]

The values of yield, based on experimental data in condition of compatibility under theoretical assumptions, are collated in Table 4 and were determined by the expression: \[ \eta = (TF/TM)/(nM/nF) = (TF/TM)/i; \] for the four loading regimes, values were obtained:

\begin{itemize}
  \item [a)] 320 rpm-engine with 32 Nm – brake \( \Rightarrow \eta = 74,190\% \);
  \item [b)] 320 rpm-engine with 40 Nm – brake \( \Rightarrow \eta = 81,956\% \);
  \item [c)] 960 rpm-engine with 32 Nm – brake \( \Rightarrow \eta = 72,827\% \);
  \item [d)] 960 rpm-engine with 40 Nm – brake \( \Rightarrow \eta = 81,323\% \);
\end{itemize}

<table>
<thead>
<tr>
<th>Brake average speed [n_F] [rpm]</th>
<th>Drive average speed [n_M] [rpm]</th>
<th>Average engine torques without the residual torque [T_M=T_M4-T_M3/Nm]</th>
<th>Average residual engine torques of the gear [T_F=TF4+TF1/Nm]</th>
<th>Yield [\eta=TF/TM/i]</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.068388119</td>
<td>-320.0272147</td>
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<tr>
<td>20.01840823</td>
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<td>-3.0637931</td>
<td>40.136568</td>
<td>81.956%</td>
</tr>
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<td>32.47974975</td>
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<td>60.07087449</td>
<td>-960.0508001</td>
<td>-6.100784185</td>
<td>40.28985173</td>
<td>81.323%</td>
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</tbody>
</table>
4. CONCLUSION
Theoretically yield of the gear reducer is determined, in classic premise, taking into account only the friction losses of cycloid gear and those from the rotation couples of the radial couplings. Under these conditions, the theoretical yield was obtained for the considered reducer: $\eta = 85.34\%$.

From the above comparison values, can thus be considered that in the manufacturing cycloidal teeth conditions, by copying after tracing, the results obtained through prototype testing confirms satisfactory the theoretical model.

5. REFERENCES

KINEMATICS OF MATERIAL POINT ON THE COCHLEOID

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Prof. PhD. Liliana LUCA, Constantin Brancusi University of Targu-Jiu

Abstract. They are shown the geometrical considerations and the properties of cochleoid, a flat curve in the spiral’s family. Determine the positions, velocities and accelerations of material point in motion on the cochleoid. They are obtained diagrams, which are interpreted.

Keywords: material point, kinematics, cochleoid

1. Introduction

The cochleoid (in English cochleoid, in Italian coceleide, Kochlias in Greek) draws its name from the snail "shell". It is a flat curve of spiral type, similar to the vertical projection of the spatial curve representing the line describing the snail shell (Fig. 1). The cochleoid was researched by J. Peck in 1700, by Bernoulli in 1726 and in 1884 by Benthan and Falkenburg.

The cochleoid is a part of the spiral’s family.

2. The cochleoid geometry. Material point positions

The BD cochleoid from Fig. 2 is described by B point on the AP radius, when P point goes on DP circle of radius AP = a = constant, with AB = ρ, the condition being that the PQ segment is equal to the BC arc, meaning:

ρ φ = a sin φ

(1)

Are written the following relationships:

x_p = a cos φ ; y_p = a sin φ

(2)

ρ = y_p / φ

(3)

x_B = ρ cos φ ; y_B = ρ sin φ

(4)
In Fig. 3 it is shown the resulting cochleoid at one complete rotation of the AP segment of Fig. 2, to \( a = 50 \) mm. Similarly, in Fig. 4 is shown the cochleoid for two full rotations, and in Fig. 5 for three full rotations. It appears that by increasing the number of rotations, it increases the number of loops near the origin of axes.

The cochleoid branches, in a rotation case, are shown in Fig. 7 (\( \varphi = 0 \ldots 180 \)), in Fig. 8 (\( \varphi = 180 \ldots 270 \)) and in Fig. 9 (\( \varphi = 270 \ldots 360 \)).

In Fig. 10 are given the variation diagrams in relation to \( \varphi \), of the curvature radius \( \rho \) and of the tracer point coordinates, B (Fig. 2). It appears that \( \rho \) is maximum in D point, then it decreases, reaching a minimum for \( \varphi = 270 \) degrees, then increases slightly, never reaching the original position. \( x_{B} \) decreases, rises and falls again, and \( y_{B} \) increases, decreases, increases and then decreases again, reaching the initial value. All curves have the same end point, at zero value.
3. Speed

By derivation the cochleoid geometry relations with respect to time, we obtain the speed of P and B points and radial velocity $\rho$.

For $\phi' = 2$ and $\phi'' = 0.5$ rad/sec/sec were obtained results in Table 1:

Radial velocity $\rho$ decreases in the negative domain, then increases, becoming positive. The velocity components of tracer material point decrease, then rise, fall and rise again, being both negative and positive.

Table 1

<table>
<thead>
<tr>
<th>Fi</th>
<th>$\text{ro}'$</th>
<th>$\text{xB}'$</th>
<th>$\text{yB}'$</th>
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**Fig. 10. Material point positions**
4. Accelerations

By derivation the speeds from relations with respect to time, we obtain the accelerations of P and B points and $\dot{\rho}$.

Table 2 shows the results for $\rho''$, $x_B''$ and $y_B''$ in relation to $\phi$. Since at $\phi=0$, $\sin \phi$ is infinite, we obtain very high accelerations near $\phi=0$. It appears that these values increase, decrease, increase again, with different sizes and domains, both in positive and negative area. Values are large at the beginning of the movement and small at the end of the movement.

<table>
<thead>
<tr>
<th>Fi</th>
<th>$\rho''$</th>
<th>$x_B''$</th>
<th>$y_B''$</th>
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<tr>
<td>170</td>
<td>38.09296</td>
<td>-1.815992</td>
<td>141.6601</td>
</tr>
<tr>
<td>180</td>
<td>37.30334</td>
<td>-37.3029</td>
<td>127.3242</td>
</tr>
</tbody>
</table>

Omega = $2 \text{ rad/s}$; epsilon = $0.5 \text{ rad/s/s}$
5. Movement modeling

They sought successive positions of AB vector radius (Fig. 2), yielding the image in Fig. 11. In Fig. 12 were represented the components of tracer point speed.

Based on Fig. 12, are written the relations:

\[ \tan \gamma = \frac{\dot{y}_B}{\dot{x}_B} \quad \cos \gamma = \frac{x_B}{v_B} \quad \sin \gamma = \frac{\dot{y}_B}{v_B} \]  \quad (5)

\[ x_E = \rho \cos \varphi + v_B \cos (\varphi + 180 - \varphi - \gamma) \]  \quad (6)

\[ x_E = \rho \cos \varphi - v_B \cos \gamma; \quad y_E = \rho \sin \varphi - v_B \sin \gamma \]  \quad (7)

\[ \Omega = 2 \text{ rad/s}; \ \varepsilon = 0.5 \text{ rad/s/s} \]

![Fig. 11. Vector radius](image1)

![Fig. 12. Velocity components of tracer point](image2)
Resulting velocity directions were sought for the tracer point. In Fig. 13 are shown these directions. Directions are accurate, but velocity vector directions require discussions, in conjunction with the variations of velocity components in Fig. 9, requiring correlation with the trigonometric circle dials.

![Fig. 13. Resultant velocity directions](image)

It thus appears that velocity vectors $v_B$ are not perpendicular to the vector rays, which is known for other curves also, except the circle [4].

6. Conclusions

The cochleoid is a curve of spirals family, similar to plan projection of space curve which is specific to snail shell.

The cochleoid branches are still being increasingly smaller with increasing the current angle.

Speed and acceleration of material point in moving on a cochleoid vary by nonlinear laws, with elevated values at first and becoming smaller towards the end of the range.

Velocity vectors are not perpendicular to the vector radius.

References

The aim of this paper is to introduce a computerized calculation program of the fractal dimension. The fractal dimension is an estimator attached to the non-euclidian forms which presents a fractal character. The article presents the increases branched copper produced by electrolytic deposition from solution of CuSO₄.

Keywords: Fractal physics, morphological estimators, image analysis.

1. Introduction

The authors have proposed a complex algorithm evaluation forms that occur in technological processes. Currently, for these forms there are not used but associative judgments which do not worth any comparison value in a concrete classification. The estimators that are introduced are those specific to the physics of fractal. Their calculation was made by a computer program developed in Borland Pascal programming language. The paper deals only with processing and image acquisition, the actual calculation of fractal estimators will be presented in another article. In the figure there are exemplified, just as information, also the values obtained in the analysis of a branched structure.

2. Experimental context

An experimental stand was manufactured in order to obtain the ramified clusters. It was made a copper dendrite analysis. The image was acquired by scanning at 300dpi esolution and size of 640x480 pixels, a pixel size being considered satisfactory to perform investigations. The gray level above a certain threshold was considered to define the cluster edge. The cluster edges are sufficiently accurate and the results of the dimensions calculations do not depend in a defining measure on the size threshold.

Fig. 1. Branched cluster, increased on rectangular support.
As we know, one of the essential characteristics of fractal objects is that they manage to pack in a relatively small zone very high perimeters, in case of two-dimensional structures, or in relatively small volumes large areas for 3D structures. If we look at 2D and to define the terms "relatively small" and "relatively large" we say that the Euclidean perimeter which delineate a surface area increases theoretically unlimited when it is a fractal object, depending on the unit size that measured it. So we can say that if:

\[ l \rightarrow 0 \text{ then } p \rightarrow \infty \text{ and } A \cong ct. \]

where: \( l \) is the length unit which made the perimeter measurement; \( p \) – the fractal object perimeter; \( A \) – the fractal object area.

These unlike the Euclidean figures where the perimeter size does not depend on the length unit of which the measurement is made. So we thought appropriate to introduce the area-perimeter relation, we can give us a measure of the complexity of object edges, a measure of the packing degree; that's why we will call it, the packing dimension. We call the packing dimension the perimeter log slope graph function of log area length unit which we measure it.

Both the generated articles by iterative functions and for the natural objects (the Cu electrolytic depositions) is measured with perimeter different lengths. It plots log (Perimeter) / log (measurement unit) and the obtained graph slope is calculated by the interpolation function. This is the packing dimension. It characterizes the subject from the global point of view. The script works with the Matlab program.

For the electrodeposition clusters we used the scanned images with the 300 dpi density and the 640 x 480 pixels resolution, with four levels of the measurement unit. With the same length unit we investigated also the single-scaled snowflakes, two-scaled and DLA aggregates. The program course is divided into four parts: 1) Binarization; 2) Filtration (purification); 3) Thinning; 4) “Box-counting” calculation method of D4 dimension.

We present below the mechanic image processing steps implemented in the software engineer. Binarization: - manual determined threshold level; - automatic fixed threshold level; - dynamic threshold level. Purification: - expansion and syncopation; - expansion and syncopation in the labeled regions order; - regions extraction on surface basis; - regions selection specifically connected; - the logic operation between two binary images.

3. General specific issues to computer imaging processing

During computer imaging processing aims at an image transformation into another image or at obtaining of certain information about an image, obviously in a smaller amount less the image contains.

An image is transformed by sampling and quantization into a two-dimensional discrete numerical sequence. The image sample wears in the special literature the name of "pixel" its value indicating - for a black and white image - a gray level. The gray level is a luminance image measure at that point. Luminance is encoded by a nonnegative number, \( g_j \), where: \( j \in \{ 0,1,\ldots,J-1 \} \). If through the process it is generated, from the initial image, another image, then it is in a sense, of a superior quality than the first. In this kind of processings we can distinguish the processings which aimed at image restoring, such as the processings which aimed at the emphasis of certain image properties. The restoration aims to the degradation effects elimination caused by optical media which propagate the image, the optical nonlinearity sensor. The image can be degraded due to noise, to the relative motion image sensor, etc. The improvement of some image features - edges, contours, etc. - in terms of their rise is obtained by processings which introduce adequate "distortions".
These distortions reveal certain image characteristics to their observation by a human operator or by the automatic extraction of features.

The processes known as image segmentation denominations, image description, image features extraction, follow image processing in a more simple one, discarded of the information "ballast". The aim is to extract some image segments to measure certain properties - area, length, curvature - and also its description for the purpose of classification or automatic recognition.

3.1. Data structure in a discretized image

A set of S pixels of an image are i-connected (where i = 4 or i = 8) if the (∀) p ∈ S and ∀ V q ∈ S and there is a pixels sequence in i-connectivity, p_j ∈ S, so that p_0 = p_n = p so p_n = q and p_j-1 and p_j are i-connected. The sequence {p_j} is a i-connected path. The path length is n.

In the figure 2 the S set is composed from the shaded region. It is octa-connected, but it isn't tetra-connected, because between p and q there are only octa-connected roads (such a road is shown in the figure).

![Fig. 2. The "n" length of a road in a octa-connected lot.](image)

The image blurring affects the contours reducing their slope. The blurring is modeled by a convolution, therefore an integration operation which acts as a low pass filter, reducing high frequencies and "deleting" the contours accordingly. It follows that for contouring should be used the emphasizing the high frequencies to operators of differentiation operators. Since sharp edges which can be emphasized can have any direction, the direction operator should be isotropic (rotation invariant).

If the noise affecting the image acts as a periodic structure consisting of fine elements which overlap the image that can be used for processing in global transforms area. Noise like "salt and pepper" may be removed by a simple method based on comparing the pixel gray level with the average gray level of its octa-connected neighbors. Threshold detection considers the pixels grey level, level which is compared with a threshold θ. The comparison result is the criterion after which the pixel is qualified as part from S or from its complementary, S_c. The threshold detection choice is an important issue for successful segmentation.

3.2. The filtration operation

The filtering operation extracts the "salt and pepper" type of noise and it applies only if it is considered necessary. The "salt and pepper" noise type appears in the image under the form of different shades points of colors against the surrounding points.
This noise type is shown below:

\[
\begin{array}{ccc}
127 & 129 & 133 \\
122 & 145 & 129 \\
121 & 120 & 125 \\
\end{array}
\]

The squares are pixels, and the numbers contained in them represent the color code (shades of gray). It is noted that the central point is totally different from the surrounding points sequence. The filtering operation involves the application of some matrix masks 3 x 3 from the next form: where \( x = 1 \ldots 10 \) and represents the share point average.

In fact each point (pixel) is mediated by its neighbors as follows: all pixels values are added in the matrix of 3 x 3 the matrix multiplications and then is divided by the weights sum. For the above examples, where the share central point (intermediate) is 2, results the new value of this item is:

\[
N=(127+129+133+122+121+120+129+2*145):10=130
\]

So, the above example will become:

\[
\begin{array}{ccc}
123 & 129 & 133 \\
122 & 130 & 129 \\
121 & 120 & 135 \\
\end{array}
\]

This filtering is very useful because from experience I found that for images with small breaks in the continuity limit through this filtering, the missing in continuity disappear. At the end of the extraction limit, it must be continuous for the lack of a single pixel would introduce gross errors in measurements.

At the end of this filtering operation it is required wrapping option of the desired area from the image that is intended to be analyzed.

3.3. The grain boundary extraction

Through this operation from the original image, which was presented in 256 colors, you get a bimounted picture. This image should contain the object limit, but on this line will be other noises like black spots and the and scattered points, etc. This operation principle is that the grain limit, having a certain range of hues, it should be detected from the image. Under this principle, things may seem to be simple only because the different reasons (visual effects camera, different lighting on the sample surface, etc.) can happen that in an area the object limit nuance is the same as a segment hue of another image area. With this in mind, based on image, many limit detection variations are possible: - manual threshold;- automatic threshold ;- dynamic threshold ;-) the derivatives method ;-) manual identification from the histogram (for very good images).

The manual threshold detection are executed by hand from the keyboard, the unit proposing different threshold values and, noting the result, it decides for one of them. The automatic threshold detection is achieved by calculating the average nuances pixels values and this value is taken as being the threshold under below which any point is considered a limit. The limit detection using the dynamic threshold is based on the idea that for each point (pixel) is calculated a threshold value, a value that represents the average of its neighbors.

From experience I found that neighboring region must be a square with sides of 20-30 pixels.Consequently for each point is calculated the arithmetic average of the gray levels, of the neighbors which are in the square with the above side mentioned (the test point is, geometrically speaking, at the diagonals intersection).
This operation is very useful because they have brightness variations.

The derivative method uses the following principle, namely: the transition from the grain boundary at the limit area takes place a sudden drop of the algebraic values of the pixels nuances and of the variation of over a derivative certain amount at the respective point. So the differences of each point from its neighbors are calculated and then the points that have greater differences than an average value, it is considered limit points. This detection method is useful for metallographic structures in which the grain limit is considered the transition area between a dominant color and another dominant color.

The manual identification from the histogram is only used if in the histogram appears clearly the nuances area of the grain boundary as the Gauss bell. With two mobile cursors this area is identified and the binarization is performed on this criterion. It appears that not only the grain limit is extracted but it appears that other components are seen as a limit. These will be further processed.

3.8. Expansion and contraction

The expansion is the operation in which each boundary point which has at least one outside neighbour (in the grain). It is added to it a number of four or eight points around. Through this is obtained what is called four neighbours expansion, in cross, or expansion on eight neighbours. Contraction is nothing but a grain expansion operation at the expense of limit. These two operations are used only both in the sequence expansion, contraction, because otherwise the structure topology is deteriorated.

Expansion and contraction can be done also with other masks in addition to those listed here. These operations are useful for "filling" of the various discontinuities caused by noise. For example, a limit stops and the space between the two ends is of two pixels. By expansion each pixel from the end lies with a further one and so the two ends are connected. The contraction operation does not interrupt this zone limit.

We stressed earlier that the grain limit, after extraction and subsequent processing, appears as a band that has a certain thickness, and the limit is considered as having the minimum thickness allowed by the image resolution. This requires the grain limit thinning without breaking it. For this purpose we have developed several thinning algorithms and further on I will present one of them.

The algorithm works on the interior grain expansion idea at the expense of the limit. This occurs successively for each grain separately. At each step is "peeling" only one pixels row from the limit, this for a grain should not particularly grow at the expense of its neighbours. An algorithm for a grain is used, the algorithm which is repeated for each grain. This works on the idea of browsing and inserting pixels which belong to the limit, pixels that have at least one connection to the grain tested. Then all these pixels being tested in terms of breaking the grain limit connectivity and will be removed those pixels that satisfy this condition. Thus obtained the limit, if it is desired and is necessary, the limits reconstruction can be done manually or automatically.

As we can note from the image, this algorithm keeps those limits which are not connected to the grain limits net than through a point or even through no one.

3.10. Limits reconstruction

This operation applies to discontinued limits in which the interruption is not greater than a few dots. The operation can be done manually or automatically. It is done manually using a cursor which will draw on the image a line between an initial point and an end point.
The automatic reconstruction operation searches on the image the points which have only one neighbour, these being end points from the limit and depending on the line direction of which it belongs is looking for another point of the same class with it. This search is done only on a few pixels away and if it finds a point, the two will be joined by a line.

With this operation end, the limit is determined and is automatically saved in the memory from this moment it can be applied the quantitative analysis methods.

Fig. 3. Illustration of image analysis for the box-counting algorithm.

4. Conclusions

Presented program brings new elements in the assessment of complex technological forms, it is easy to use and is intended to be a handy tool for the technologist engineer.

Original elements in the acquisition and image analysis: designing a language program in Borland Pascal 7.0 for the implementation of the fractal dimension calculation Dq method "box-counting"; designing an algorithm for image thinning limit; the implementation of a procedure for image thinning limit; the development of an expansion and contraction procedure of the grain limit; the development of a procedure for scanning the image with the exploration line for the linear analysis method; the development of a filtering image procedure.

Section on methodology for calculating the fractal estimators will be presented in a future paper.

References

BRIEF ON THE COMPOSITE ELECTRODEPOSITION

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Abstract: Development of materials deposition was determined by scientific and technical material requiring special properties that cannot be produced by other processes, or special surface properties of common materials. They were introduced in almost all sectors: aeronautics, mechanical engineering, metallurgy, food industry etc.

Keywords: composites, electrodeposition, mathematical models

1. Introduction

In research done in time, submissions were made in layers with variable thickness, were deposited coatings on parts with complex geometric configuration of the basic material properties that give us able to meet user requirements (corrosion protection, tribological properties, optical, thermal, decorations, etc.). To obtain a deposit which is required to have special properties, primarily meet the technical imperatives of protection against corrosion, resistance to friction, wear, high temperature, high hardness, etc., to satisfy the conditions of service and reliability.

The composite material is a set of two or more macroscopically homogeneous materials with different structure and properties, combining the qualities of individual components, forming a heterogeneous material with improved overall performance. Therefore, a composite made up of at least two components, one-function matrix, the other box in first, with different shapes and sizes, serves as reinforcement, with clear-cut separation surfaces [1].

Composite materials are extremely varied, depending on the nature of the matrix, the nature, form and size of reinforcement. Depending on the nature of matrix composite materials can be: metal-matrix composites, plastic matrix composites, ceramic matrix composites, carbon composites.

Depending on the nature of reinforcement, composites can be reinforced with: carbon fiber, glass, carbides, oxides, nitrides, metals, etc.. in different shapes and sizes. Composite coatings can be divided into five types:
- coatings (layers) to wear and abrasion resistant;
- coatings (layers) with self-lubricating properties;
- coatings (layers) of dispersed high toughness;
- coatings (layers) for finishing the surface to improve resistance to abrasion and oxidation;
- coatings (layers) active.

2. Layers of different types of composite matrix

2.1 Layers of nickel matrix composite

In nickel, the matrix may be incorporated into any kind of particle, the particle suspension that the electrodeposition of nickel electrolyte. Codeposition of SiC in the matrix of nickel induces a high hardness deposited layers. Carbides of tungsten, chromium, titanium and nickel matrix are studied electrocatalytic effects, in order to replace precious metals. Electrodeposition of nickel sulphides in the matrix was developed as an alternative to lubrication or catalytic activity electrodes produce hydrogen for various processes in the evolution of electrocatalysis.
Diamond particles introduced into the nickel matrix leading to fine grinding surfaces needed in dentistry.

A true revolution in obtaining new metal matrix composites is the introduction of liquids by codeposition microcapsules containing liquid and enjoy certain properties:
- manufacture of self-lubricating surface properties by codeposition oil microcapsules;
- increased resistance to corrosion by introducing corrosion inhibitors;
- production of metal foam type structures, obtained after heat treatment of liquid metal composites.

This is a process in which micro-fine droplets of liquid are surrounded by a coating to give small capsules. These microcapsules consist of a liquid interior surrounded by a solid wall, called a shell, shell or membrane. This coating is often a natural or synthetic polymer. Capsules with sizes between 1 and 1000 nm are called microcapsules. Processes known for producing microcapsules with liquid inside is divided into three categories:

- interfacial polymerization;
- in-situ polymerization.

2.2 Layers of copper matrix composite

The most studied copper matrix composite layer is obtained by codeposition of aluminum oxide. Best corrosion resistance is a copper matrix composite layer and zirconium oxide. Obtaining copper matrix composite layers with dispersed particles of sulphide with resistance to wear and use against friction. As codeposition sulfides are sulfides of molybdenum and tungsten. The electrodeposition of carbon in copper matrix, composite layers obtained gives special lubricating properties, being used as solid lubricant and is the oldest composite coating obtained by electrodeposition. Compared with molybdenum disulphide, graphite is more effective in copper matrix, to reduce friction wear. Codeposition red phosphorus particles in the matrix of copper from acid copper plating bath, is a method of obtaining copper fosforizat which is preferred as anode material in shiny copper plating. The inclusion of chromium carbide in nickel-cobalt alloy matrix, gives a high resistance to wear elastic deformations.

Tribological studies of dry friction at temperatures between 20°C and 750°C, demonstrated the superiority of the composite obtained by electrochemical codeposition. Wear resistance and temperature electrodeposition of silver can be improved by codeposition of aluminum oxide particles. Matrix composite layers of gold dispersed particles of aluminum oxide are also reported to improve their wear resistance. Nickel-phosphorous alloys obtained by chemical reduction is very good matrix composites in obtaining thin layers with aluminum oxide as dispersed phase. Also in these alloys can be codeposited fine particles of zirconium metal and miobiu.

2.3 Polymer composite coatings

Ultrafine polymer films can be deposited on polymers by electrochemical polymerization method. Such films adhere well to the substrate, are chemically stable to the action of liquid electrolytes and inert electrodes can confer catalytic activity. The catalytic activity can be increased by incorporating metals in the form of clusters. Electrochemical process can take place at the interface of polymer / electrolyte and the electrons are transported through the polymer film.
Polymer is deposited on a metal substrate, usually platinum \([6,7,8]\). This process takes place in two stages:
1. electron transfer from / to the electroactive species in solution (from) the surface of the polymer.
2. electron transport through polymer film
Polymer matrix acts as a membrane, allowing the electroactive species and electrolyte to pass the underlying metal surface / polymer, a region in which the load reaction transfer.

3. Mathematical models for the electrolytic codeposition
Mathematical models have been proposed from experimental observations on the codeposition of a composite system.

3.1 The proposed Saifullin model calculates the percentage of the composite layer as follows \([3]\):

\[
Wt\% = \frac{m}{m} \times 100\% \tag{1}
\]

Where:
\(Wt\%\) = weight percentage of particles incorporated into particles; \(m\) = the mass of particles in a composite layer cm\(^3\); \(m\) = the mass of a composite layer cm\(^3\).

Bazzard and Boden's model proposed the formula \([4]\):

\[
wt\% = \frac{4}{3} \frac{r_p^3 \rho m}{r_p^3 \rho m + 4\pi r_p^2 \epsilon_m i t} \tag{2}
\]

where:
\(\epsilon_m\) = the electrochemical equivalent of metal; \(r_p\) = the particle radius; \(t\) = the time of submission;
\(i\) = current density

3.2 Guglielmi's model
It has the following formula \([2]\):

\[
\frac{\alpha}{\alpha - 1} = E (B-A) \eta \tag{3}
\]

where:
\(\alpha\) = volume fraction of particles in the deposit; \(n\) = valency of metal; \(F\) = Faraday's constant; \(\rho\) = density of metal; \(\eta\) = surge; \(B, A, V_o\) = constant; \(I_o\) = exchange current density; \(k\) = constant, which depends on the interaction between particles and cathode; \(C_v\) = volume fraction of particles in suspension.

3.3 The model proposed by Celis, Roos and Buelens
For mathematical treatment of the dispersed codeposited particles, are assumed to be stationary conditions achieved, so that the concentration, temperature or pressure do not vary during the process and the cathode surface is uniformly accessible to the electrolyte suspension. Quantitative description of the incorporation of a particle in a growing metal matrix can be assessed by a statistical relationship, the coefficient \(P\) is the probability that a
particle is codeposited, and \( N_p \), the number of particles passing through the diffuse double layer the electrode in unit time and per unit area. Increasing weight composite layer, per unit time and surface area, \( \Delta W_p \), resulting from the incorporation of particles, can be written as follows [5]:

\[
P = N_p W_p \Delta W_p
\]  

where: \( W_p \) = weight of a particle; \( N_p \) = number of particles passing through the diffuse double layer. Spherical particles are considered, the weight of a particle is:

\[
W_p = \frac{4\pi r^3}{3} \rho_p
\]  

1. Electrolytic deposition of composite coatings of nickel-phosphorus matrix and hard SiC particles

Development of composite materials require special facilities that are able to ensure optimal conditions for development. To obtain layers which have remarkable properties, electrolytic cells where these deposits are obtained has to ensure optimal working parameters. The figure 1 presents a cell equipped with special equipment to maintain the electrolyte temperature, electrolyte agitation and to provide for moving parts [9].

![Fig. 1 The electrodeposition cell for composite layers](image)

This cell type is a bustle of elecrolitului suction at the bottom of the tank with a pump peristatică. Temperature is ensured by an oil bath which is in a cell with double walls. Electrolyte return is calibrated through distributors willing electrolyte surface. Replacing the electrolyte is in part controlled by the pump speed. Electrolytic process development work in complying with conditions such as electrolyte composition, pH, temperature and agitation. Important experimental results of hardness, wear, corrosion, etc. are made to change the content of phosphoric acid in the electrolyte (Fig. 2).
The amount of phosphorus incorporated into the layer increases with increasing content of phosphoric acid in the electrolyte. The content of phosphorus incorporated into the layer evolves as both composites and solid solutions without particles. In the first part of the curve, where the content of phosphoric acid in the electrolyte is low and where are microcrystalline alloys, particulate phosphorus content changes little. The increase included phosphorus layer is observed that incorporation of phosphorus is higher at increasing the amount of silicon carbide particles.

Also the number of particles deposited per unit area depends on the electrolyte content of phosphorous acid and phosphorus content of the default layer. Increasing the content of hard particles increases the quantity of particles deposited per unit surface layer and the amount of hard particles is not constant codeposited on the whole composition domain. This phenomenon is especially striking with hard particles as the electrolyte concentration is higher [9]. For deposits with high content of hard particles begin to saturate the amount surfaces low content of phosphoric acid. For deposits with a lower concentration of hard particles that saturate of particles quantity per unit mass is lower, but still noticeable.
5. Conclusions
Electrodeposited metal matrix layers are a solution to increase performance and reliability of parts.
Metal matrix composite deposits and phases built tough with the role of reinforcement are part of advanced materials currently being studied as layers tribological properties. Incorporation of hard particles in metal matrix composite obtained electrodeposited is a complex process that requires additional parameters to the metal deposits and their strict observance (electrolyte, agitation, temperature, pH). Alloy layers and Nip Nip matrix composites were made by hand in the electrolyte.
There are studies on the influence of working conditions (temperature, amount of chemical compounds in the electrolyte, etc.) layer on the characteristics. It was found that increasing the content of phosphoric acid in the electrolyte between 5% and 20%, we get an increasing amount of phosphorus incorporated into the phosphor layer and deposited layer that is evolving as both composites and solid solutions without particles.

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METHOD AND PROCESS OF AUTOMATIC WEIGHTING OF PYROTECHNICAL PRODUCTS

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Abstract: In this work, the authors present researches result for the amortization of free flutters in the process of automatically weigh pyrotechnical products in the shape of nubs. The study of free flutters is the beginning stage for realization of a machines of weigh and automatic sorting. There fore the authors present the own solutions of quick amortization of the oscillations of the arms of the balances installed on the rotary platter of the machine.

Keywords: The free vibrations, liquid damper, quick amortization of the oscillations, lever balance, amortization time, machine of weigh and automatic sorting.

1. Introduction
In the pyrotechnical industry is achieved many products whereat the weight of the components elements contribute integral for obtaining the technical and dynamic parameters of performance [1]. Came in the the support of the manufacturers of such products, the present author of the item, presents from theoretical viewpoint and then on an experimental model, influence of free flutters of the balances about the accuracy of weigh and for amortization of these in the sight of a realization automatic high-perfor-mance machines.

Fig.1. Systems with translational and rotation motions.

2. Theoretical notions
The free vibrations are the characteristic compliant of the figure 1a and 1b incite the which systems executes the translational motions as much as those who executes a rotation motion [2]. In case of rotation motions, the equation of motion is expressed with the relation:

\[ I\ddot{\varphi} + K\dot{\varphi} + c\varphi \pm M_f = 0, \]

Where: \( I \) = The moment of inertia of the mobile system; \( K \) = Constant of the bow 2; \( c \) = The amortizations coefficient of the damper 3; \( M_f \) = The friction moment from the encampment \( A \); \( \varphi \) = The amplitude of the vibrations of mobile system.

The solution of differential equation (1) is:
\[ \varphi = \varphi_o e^{-\beta \omega_o t} \left[ \frac{\beta}{\sqrt{1 - \beta^2}} \sin \left( \omega_o t \sqrt{1 - \beta^2} \right) + \cos \left( \omega_o t \sqrt{1 - \beta^2} \right) \right], \quad (2) \]

Or under the shape:
\[ \lambda = \frac{\varphi}{\varphi_o} = e^{-\beta \omega_o t} \left[ \frac{\beta}{\sqrt{1 - \beta^2}} \sin \left( \omega_o t \sqrt{1 - \beta^2} \right) + \cos \left( \omega_o t \sqrt{1 - \beta^2} \right) \right], \quad (3) \]

The equation (2) is valid if \( \beta < 1 \) where by \( \beta \) (the degree of damping) was noted the proportion:
\[ \beta = \frac{c}{2\sqrt{IK}} \quad (4) \]

For \( \beta > 1 \), the solution of differential equation (1) is
\[ \varphi = \varphi_o e^{-\beta \omega_o t} (1 + \beta \omega_o t). \quad (5) \]

Which, for \( \beta = 1 \) acquire the form:
\[ \varphi = \varphi_o e^{-\omega_o t} (1 + \omega_o t). \quad (6) \]

In this relations, \( \omega_o \) describeth the proper pulsation of the system and it’s determinate with the relation:
\[ \omega_o = \sqrt{\frac{K}{I}} \]

In the figure 2, according [1] are represented the possible shapes for the oscillation of the mobile system, compared with the unamortized oscillations of this (the equation of the unamortized motion have the form:
\[ \varphi = \varphi_o \cos \omega_o t \]

To the projection of dampers for free flutters, it concerns to determine of such nature the degree of amortization \( \beta \) or the coefficient of amortization, so that the oscillation \( \varphi_o \) of mobile system to attenuated in a short time, to its admissible value (the amplitude \( \varphi_n \) of reading or registration).

Is accustomed in the calculi, to expressed this thing by a parameter \( \lambda_a \) that is caused with the relation:
\[ \lambda_a = \varphi_n / \varphi_o = e^{-\omega_o \beta_n t}, \quad \Rightarrow \lambda = \lambda_a, \text{ for } \varphi = \varphi_n \]
Although the solutions with \( \beta > 1 \) are effective from viewpoint of the amortization capacity of oscillations (practically the oscillation of the mobile system disappear) in machines is used the amortization with \( \beta < 1 \).

For the solution \( \beta < 1 \), it will be calculated the \( T \) parameters (the period of amortized vibration) and \( \omega \) (the pulsation of amortized vibration) with the relations:

\[
\omega = \omega_0 \sqrt{1 - \beta^2},
\]

\[
T = \frac{2\pi}{\omega} = \frac{T_0}{\sqrt{1 - \beta^2}}
\]

Where the undamped period of oscillations \( T_0 \) is:

\[
T_0 = \frac{2\pi}{\omega_0}
\]

The time \( t_a \) till it reach the amplitude \( \varphi_n \) is called amortization time and can be obtained by resolving the differential equation of motion. It can be determine approximately with the relations:

\[
t_a = \frac{2I}{e} - \ln \lambda_a, \quad \text{if} \quad 0(\beta) < 7
\]

The calculation confirmed by practice show that if its modified the amortization degree of mobile system oscillations from \( 0 \) to \( \infty \) the amortization time \( t_a \), at the beginning it will diminish, and after the reach of minimum it will propagate. The minimum time of amortization, \( t_m \), correspond an optimal degree of amortization \( \lambda_{op} \) which it is obtained for \( t_a = \frac{T}{2} \) (figure 3).

Through observance of this condition and following the expressions (7) and (8), for \( \omega \) and \( T \), the relation can be written under the format:

\[
\lambda_a = \frac{e^{-\beta_{op}}}{\sqrt{1 - \beta_{op}^2}} \quad \text{or} \quad \beta_{op} = \ln \frac{\lambda_a}{\sqrt{\pi^2 + (\ln \lambda_a)^2}}.
\]

The relationship of minimum time of amortization \( t_m \) in proportion with \( \lambda_a \) its obtained from relation (3), by replacing the value of \( \beta \) with \( \beta_{op} \).

3. The experimental model proposed

For automatic weighing of a greater number of products or elements in the time unit, the author has designed and accomplished an experimental model of a lever balance, shown in figure 4.

The first balance (figure 7) is one of the 24\(^{th}\) mechanisms of weighing set on the rotating dish 2 of an automated machine design in this purpose, giving the centre of weight on the rotation axis [1].
On the right part the balance arm was designed with a support 2 (figure 4), which is set the weighing products, and on the left part with the equilibration piece 12. For amortization of free flutters that are produced when the weighing piece is put on the support 2, we have designed an liquid shock absorber who is composed from glass 4, dish 5, chain connection 6 and the dipping deep adjustment screw 7.

Depending on the viscosity of the liquid, on the surface of the dish it’s creating intermolecular friction and interaction forces between the dish and the liquid which are opposing the movement. Thus, after a while, the free flutters of the arm 8 it’s amortized, and it equilibrates. On the left part, the arm was provided with a counterweight 12, with possibility of adjustments, and a knife 13 for conducting the arm 8 onto one of the three guides of the machine, depending on the weight of weighing product.

That the dynamic shock produced on the felt of the product 1 on the support 2 do not determine the knives to move from its fulcrum, on the support of the balance we have installed the spring chair 11. The height of it was adjusted so that the knife 13 can be displaced without any friction through the guideway III appropriate to light products, (figure 5). The guideways for automatic selection 2 were installed according to figure 6 on the central fixed axle 4 of the machine. The guideways were conceived to select the products in three categories of weight:

![Fig. 4. The experimental model of a lever balance](image)

![Fig. 5. The guideways for the knives.](image)

![Fig. 6. Sectional guideway.](image)
First category – normal products which are situated in the nominal value of weight $G_{\text{nom}} \pm 0.1\%$;
Second category - more heavier products than $G_{\text{nom}} + 0.1\%$;
Third category – lighter products than $G_{\text{nom}} - 0.1\%$.

4. The measurements results

In that the quality of weighing depends on the minimum time of amortization of free flutters and the spinning speed of platter the port balances, (figure 7), the author studied more types of viscous liquid, compared with water. The measurements results are shown in table 1.

The measurements results

<table>
<thead>
<tr>
<th>No.</th>
<th>Utilized liquid</th>
<th>The conventional sliminess at 372 °K [°]</th>
<th>The amortization time [s]</th>
<th>The no. of oscillations till total amortization</th>
<th>The weight of weighing product [g]</th>
<th>The heights of fall [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>water</td>
<td>-</td>
<td>16</td>
<td>7</td>
<td>8.6</td>
<td>6</td>
</tr>
<tr>
<td>2.</td>
<td>HA oil</td>
<td>3.5 – 4.5</td>
<td>3</td>
<td>2</td>
<td>8.6</td>
<td>6</td>
</tr>
<tr>
<td>3.</td>
<td>T90 oil</td>
<td>3.0 – 3.5</td>
<td>3</td>
<td>2</td>
<td>8.6</td>
<td>6</td>
</tr>
<tr>
<td>4.</td>
<td>M20/W40</td>
<td>9.0</td>
<td>5</td>
<td>3</td>
<td>8.6</td>
<td>6</td>
</tr>
<tr>
<td>5.</td>
<td>Silicones liquid</td>
<td>4.5</td>
<td>2</td>
<td>1</td>
<td>8.6</td>
<td>6</td>
</tr>
</tbody>
</table>
5. **Conclusions**

After the experimental data processing were related the following conclusions:

1. The liquid shock absorbers are the most simple and effective solution for the amortization of free flutters produced in the arm of a balance at the falling of a weight from a small height.

2. The amortization of free flutters is done so much faster as the liquid is more stickier and is more dense.

3. The silicones liquid is the best liquid for amortizations of free flutters.

4. Because the amortization of free flutters can be done in maximum three seconds, result that for a platter, it can be efficiently installed three charger with products, according figure 7.

**References**


SHOCK PROTECTION DEVICE FOR ROTATION SENSORS

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Abstract: Starting from a virtual model of a device designed to investigate friction force effects in colliding mechanical systems, the authors have developed a test-rig. The friction force effects had to be estimated using a rotating sensor. Finally, to protect the sensor from shock effects, a constructive solution is proposed. The accuracy of the new device is estimated using FE analysis.

Keywords: impact mechanics, shock sensor protection, spatial mechanism, FEA simulation

1. Introduction

In a series of recent papers, the authors, [1], [2], [3], [4], were concerned about impact phenomena, particularly how the friction forces influence different kinematical and dynamical parameters of the system. The importance of the effects of the phenomena that occur with sudden variation of the parameters was emphasised for the last decades, due to the progress achieved in the computing technology domain that allowed a multi-body theory approach of dynamic aspects concerning the mechanical systems, Wittenburg, [5], Shabana, [6], and Nikravesh, [7].

There are theoretical approaches, more or less complicated, trying to describe the dynamical behaviour of a system where collision phenomenon takes place. Based on these theories, softwares were created to describe the behaviour of such systems.

Regardless of the complexity of the theory of software, applying these requires experimental results a good agreement between the modelled results and the experimental ones. The tests concerning impact phenomena imply surmounting two interrelated aspects, namely: first, the extremely reduced time of impact and, second, the really high values of contact forces. The later obliges considering protective measures upon control instrumentation.

2. Theoretical remarks

The impact phenomena are studied via two approaches. The first, considers an instantaneous collision of rigid bodies, according to Brach, [8]. The variation of different parameters is expressed using several coefficients from which the most well-known is the coefficient of restitution (COR), defined as the ratio with changed sign between the normal components of relative velocities of contact points, after and before collision. For friction collision, Brach introduces two coefficients of restitution, characterizing tangential component of velocity variation and angular velocity, respectively. The weak point of this model is the impossibility to estimate the impact forces and torque, as the instantaneous collision conducts to infinite force values. A second study manner concerns the continuum model that considers a continuous parameters’ variation during the impact. For undumped collision, the solution of the problem is given by Timoshenko, [9], and for dumped collision, the model is based on works due to Dubowsky and Freudenstein, [10], and Hunt and Crossley, [11]. Starting from a Kelvin Voigt model for two colliding bodies, with the remark
that the hysteresis loop is opened, the later propose a modified equation of the model with the aim of obtaining a closed hysteresis loop. Lankarani and Nikravesh, [12] continue the theoretical research carried out by Hunt and Crossley, [11] and, for describing the central collision of two spheres, give the following equation:

\[
F = K\delta^n \left[ 1 - \frac{3(1-c_e^2)}{4} \frac{\dot{\delta}}{\delta_0} \right]
\]  

where \( K \) is a constant that takes into account the elastic characteristics of the two spheres and the local geometry in the vicinity of contact point, \( c_e \) represents COR, \( n \) is a power exponent of force-deformation relation for a Hertzian contact; for the two spheres in contact, this takes the value \( 3/2 \), according to Johnson, [13]. The normal approach is denoted \( \delta \), and \( \dot{\delta}, \dot{\delta}_0 \) represent the velocity and the initial impact velocity, respectively. The equation (1) can be applied only for stiff bodies, when \( c_e > 0.9 \). Recently, Flores, [14], proposed a modified form of equation (1) that can be applied for soft materials, too. This modified form is:

\[
F = K\delta^n \left[ 1 - \frac{8(1-c_e)}{5c_e} \frac{\dot{\delta}}{\dot{\delta}_0} \right]
\]  

This concise review ought to include the monographic work of Goldsmith, [15], wherein besides theoretical aspects, very useful experimental results are presented.

3. **Subject argument**

Aiming to find experimentally the friction force, as value and effects, from collision, the authors proposed a dynamic model consisting from a mathematical pendulum, having a cylindrical rod ended with a steel ball, [1], as shown in Figure 1. The ball collides with the frontal face of a steel cylinder rotating about its own revolution axis. The pendulum oscillates around the joint denoted by \( B \). By introducing a revolute joint, \( C \), with the axis along the pendulum rod, the pendulum may rotate around the rod axis. During collision, the normal impact force generates a friction force responsible for the ball rotation around the axis of \( C \) joint. The friction torque and the friction force can be found by measuring the variation of angular velocity. The dynamical behaviour of the system was simulated via ADAMS software. The Figure 2 presents the normal contact force variation and it can be observed the appreciable magnitude, in the order of \( 10^3 \) Newton. For a theoretical estimation of normal contact force, the authors applied a combined analytical and numerical integration method and integrated the equation (1). The collision of two identical steel balls, of mass \( 1kg \), impacting with initial velocity \( \dot{\delta}_0 = 1m/s \), was considered. Figure 3 presents the variation versus time of contact force and Figure 4 present the dependence of contact force on normal approach \( \delta \). In Figure 3, in abscissa, the dimensionless time, as ratio between time and the undumped impact duration \( t_H \), (value mentioned on Figure 3), was considered. In Figure 4, in abscissa was considered the ration between the normal approach and the maximum undumped approach, \( \delta_H \). It can be noticed that the results for normal contact force from FEM-ADAMS simulation are comparable to the results obtained theoretically.
The high values of contact impact forces generate important reactions in mechanism’s joints where collision phenomenon occurs. Therefore, special protective measures upon control instrumentation should be considered.

4. The experimental test-rig and improving solution

Based on the model presented in Figure 1, an experimental device was constructed and it is presented in Figure 5. The angular velocity was intended to be measured using a rotation sensor placed on the rig frame. The rotating motion from the axis of the pendulum is transmitted using a rubber belt, stretched by two rolls, one fixed on the sensor’s shaft and the other one, denoted roll 1 and placed on the pendulum’s shaft. This belt transmission system is ineffective because at large launching amplitudes of the pendulum, either the belt bounds the roll, or, if remaining on the roll, the sudden angular velocity change produces belt slip over the rolls and the results are erroneous. Consequently, for accurate results, the sensor should be placed directly on the pendulum’s shaft. The inconvenience of this solution consists in significant inertial forces arising during collision, capable of damaging the sensor.
To get rid of this inconvenience, the next solution was adopted: the sensor was placed using an auxiliary mechanism having the degree of freedom: $DOF = 2$. The driving motions of this mechanism, presented schematically in Figure 6, are the oscillating motion and the rotation motion around the rod axis. The mechanism consists of the frame, $\theta$, the pendulum (elements 1 and 2), and supplementary elements 3 and 4. The pairs of mechanism are: four revolute joints, namely: $B$, $C$, $E$ and $F$ and a cylinder-plane high pair joint, $D$. The degree of freedom of the mechanisms is:

$$DOF = 6(5 - 1) - 4 \cdot 5 - 1 \cdot 2 = 2.$$ (3)

The normal reactions from the revolute pair, $F$, will be taken by the frame and thus only the rotation motion will be transmitted to the shaft of the sensor. The mass moments of inertia for the mobile elements of the sensor are negligible and it results that the inertial torque acting on it is also insignificant and therefore, the sensor is protected from sudden changes of kinematical parameters.

Another aspect to be mentioned concerns the effect upon the accuracy of the results given by the supplementary elements 3 and 4 positioned between the sensor and pendulum. An analytical study is difficult to perform, as Yang, [16], demonstrates, but, as the model of the mechanism is obtained via CAD methods, a kinematical analysis using specialised software can be used to observe the response of the system at different input motions. As driving motions were considered: a sinusoidal dumped oscillation, with an initial launching angle of $60^\circ$; for axial rotation, it was assumed that for every impact the pendulum revolves with the same angle. The results are presented in Figure 7 and Figure 8. From Figure 8 it can be noticed a difference between the signals from the joints $C$ and $F$. This dissimilarity can be significantly reduced if the launching angle of the pendulum is less than $20^\circ$. For the case requiring a greater initial impact velocity, the launch can be made using a spring but a procedure for finding the initial impact velocity is needed. Figure 9 presents the variation of the parameters from figures 7 and 8, for a launching angle $20^\circ$. One can observe that the revolute angles from $C$ and $F$ joints are identical, but of opposite sign.
Fig. 6 Auxiliary mechanism for avoiding sensor’s damage

Fig. 7 Revolute angle variation in B and E joints

Fig. 8 Revolute angle variation in C and F joints

Fig. 9 Positional parameters in revolute joints of mechanism
5. **Conclusions**

The paper presents a review of the main aspects concerning impact studies and a proposed virtual model completed using ADAMS software, for studying the friction forces from colliding systems.

An experimental device was designed based on the virtual model and constructed in the laboratory to study the friction force effect during impact. The friction impact effects are estimated using a rotation sensor. An initial design solution proved unsuitable and a new solution is proposed allowing the use of the same sensor and protecting it from shocks.

The agreement between the rotation of driving element and the signal of the sensor is estimated using a FE model.

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**References**

LAMINATED OBJECT MANUFACTURING-LOM

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Abstract: The fabrication of stratified pieces (LOM) is a fabrication method where a 3D model is constructed by adding, pasting and cutting the sections in a cycle that repeated starting with the first layer at the bottom of the piece and ending by the last layer at the top of the piece.

Keywords: laminated, polyvinyl, rapid prototyping;

1. Introduction

The fabrication as quick as possible, with a cost as reduced as possible of a model or of a new product has been a dream of any technologist engineer. Starting with the ‘90s, this dream has turned into reality every day due to the appearance and the implementation in the industrial practice of the technologies of quick fabrication of prototypes (Rapid Prototyping - RP) that are basically different from the technologies known and used until that moment.

As a notion, the quick prototyping is associated to a number of relatively new technological proceedings allowing the quick accomplishment of the physical model, of the functional prototypes, of the reference points, of the sub-ensembles or of the tools involved in the developing process of the product.

These techniques of quick prototyping use another principle for materializing the piece, by adding material as much as needed and where it is necessary for the tools.

The result followed by applying these technologies is the accomplishment in a short term and with a negligible additional investment of a limited number of samples of:
- the actual product;
- a copy (full-scale or made of another material) of the product in different stages of development;
- tools and devices necessary in order to achieve the product, in order to validate the creation conceptions to the current phase, different tests and the following orientation of the developing approach of the product.

A classification of the quick fabrication technologies of the prototypes suggests a grouping of these technologies in two categories:
- forming technologies by depositing material;
- modelling technologies by sampling material.

The method studied in this paper is Laminated Object Manufacturing (LOM).

The principle: The first LOM fabrication system was developed in 1991 by Helisys company. In LOM, the obtaining of the layers composing the piece is made by cutting from a sheet of solid material (paper, polyvinyl), by using a cutting element (infrared laser, diamonded point knife, etc)(fig.1).

The material that does not form the current layer will be removed by hand at the end of the process. Once every layer is finished, it is connected to the previous one, by using an adhesive (placed on the inferior side of the sheet) activated or not by the heat.
At present, there are several materials used for LOM: paper, plastic or composites. At the end of the process, the piece is wrapped in the material in excess that must be removed; due to this fact, the LOM process is the most adequate for small or average sized pieces without complicated details.

Advantages: good accuracy, big scale construction. Disadvantages: a limited scale of materials, weak properties of the materials, the support removal is needed.

The devices used in order to obtain such pieces in a Rapid prototyping system are called 3D Printers.

2. Work Principle

The fabrication of stratified pieces (LOM) is a fabrication method where a 3D model is constructed by adding, pasting and cutting the sections in a cycle that repeated starting with the first layer at the bottom of the piece and ending by the last layer at the top of the piece.
The model of the 3D printer on which there were accomplished the experimental researches presented in this paper is Solido SD 300 Pro (fig.2) and it belongs to the Researching Laboratory of the Industrial Engineering Chair within the Engineering Faculty of “Constantin Brâncuși” of Târgu Jiu.

In the first place, the piece is represented 3D by means of a graphics programme assisted by the computer, for example: AutoCAD, Solid Works (fig.43), CATIA, etc, and then it will be saved in a *.STL file (fig.5).

This method of quick fabrication starts from the *.STL file of the piece to be processed, that is also taken over by the soft of SOLIDO SD 300 PRO device. We accomplish the sectioning of the 3D model in layers of equal width with the width of the sheet of chloride polyvinyl and we calculate automatically the profile of the piece of every section, which will be cut by means of the cutting point.

![Fig.4. 3D show piece. (Solid Works)](image1)
![Fig.5. *STL file.](image2)

The cutting starts with the inside/outside profile of the section by the piece at the respective z level. Then, it is the cutting according to the hatching of the material in excess and it ends by the cutting of the inside/outside profile of the box.

Next, the sheet advances at the same time with the width of a layer so that at the previously built package we add a new layer of material. The roll of adhesive depositing will scroll on the surface of the new layer of material and will paste it on the previous layer by adhesion and pressing.

Then, we go back to cutting and the construction process of the piece ends when the height of the package contracted by depositing successive layers of material reaches the $z_{\text{max}}$ level of the piece.

SDView software is an application of 32 bytes, with the interface with dialogue windows, progress indexes etc. SDView is completely integrated with the device equipment, allowing the pre-processing, the execution of the sections by the piece and the control of the device in only one programme.

The lamination system is represented by a roll of chloride polyvinyl sheet (fig.6.a), whose position to the working platform is controlled by means of a micro-switch.

The layers adhere one to another by means of an adhesive distributed on the sheet surfaces right when it advances in order to constitute a new layer, by means of a depositing roll.
In order to detach more easily the elements that will subsequently be removed, in the respective areas the device deposits an anti-glue that annuls the pasting effect of the adhesive previously deposited on the entire surface (fig.6.b).

The fabrication time depends not only on the piece gauge but also on its complexity featured by the number of triangular plan faces by means of which it can be estimated.

3. Experimental results.

The piece – Gasket – was modelled 3D (fig.4) by means of the Solid Works graphics programme and saved in a *STL format.

STL is a file format native for the CAD Systems 3D stereo-lithography softwares. This file format is carried by many types of software used on a large scale in order to accomplish Rapid Prototyping and by a fabrication assisted by the computer.

The *STL files describe only the tri-dimensional geometry of the surface of an object, with no representation of colour, texture or other attributes common to CAD model.
Thus, due to the existence of the 3D model, by means of the SDView soft, the printer has constructed the piece resulting the prototype, layer by layer (fig.7.a).

After completing (detaching) the piece, the remained material represents the waste that is, unfortunately, irrecoverable (fig.7.b).


We have tried to find the optimal technological parameters for every piece, considering its features related to the form, the gauge, the required accuracy, etc.

By means of the accomplished experimental researches, of the fabrication of the RP models on the SOLIDO SD 300 PRO device, there were brought important constitutions in the following directions:

- optimizing the technological parameters for cutting in X-Y plan;
- optimizing the pasting system of the successive layers, in order to improve the accuracy in the Z axe of the fabricated piece;
- optimizing the orientation of the pieces during the construction;
- the possibility to estimate the behaviour of different types of LOM models, in certain work conditions, by means of a better comprehension of the fabrication process.

One of the evaluation criteria of the FRP technologies is the accuracy of the RP fabricated models, especially because accuracy is not a strong point for any of the FRP proceedings. These FRP technologies have many advantages (referring to the possibility of quick fabrication of some pieces, as complex as they are), but the accuracy is comparable to the one obtained by the classical technologies of lathing, finishing of finishing milling.

It was also found that the main factors influencing the immediate and long-term stability of the shape of the LOM models are:

- the comprehension force of the roll that pastes and presses the layers for pasting. This comprehension force creates residual tensions contributing to the change of the piece shape, after finishing its fabrication.
- the inter-laminar tensions of the adhesive layers that, after pasting, suffer distortions causing residual tensions, too.
- the lack of compensating the radius of the cutting knife causes errors in the x-y plan.
- the humidity absorption of the sheet used for the fabrication of the LOM pieces also provokes significant elongations of the model sizes.

Even if the process enjoys a large industrial use, we consider that, in the future, we will have to intensify the researches for the analysis of the LOM process, by a modelling of a process, by using methods of computational analysis that should consider the pressure, the temperature, the thermal transfer, the humidity etc.

Anyway, by means of the accomplished experimental researches, we have also tried to bring an important contribution to a better comprehension of the LOM process and to the possibility to estimate the behaviour of certain shapes of pieces in certain conditions.

The LOM system offers a lot of flexibility regarding the system parameters: the cutting speed of the cutting point, the speed of the pasting roll, the roll temperature, etc. This flexibility sometimes involves difficulties, complexity and confusion, too.

In order to remove a few of these negative facts, we have accomplished experimental researches (by using SOLIDO SD 300 PRO device) regarding the influence of two of the most important factors of the LOM process: the pasting process and the cutting one.

As a result of numerous accomplished experiments, it was found that, when fabricating a new piece, the operator should always follow a procedure of optimizing the
technological parameters that, after choosing the type of the layer material and the cutting speed, should choose the actual cutting speed desired by him and then he should adjust it depending on the used cutting speed, in order to find the adjusted power that will actually be the value introduced as a parameter of setting the laser power, when fabricating this piece.

The pasting process of the successive layers during the fabrication of the pieces on the LOM device depends on the following factors:
- the speed of the pasting roll;
- the temperature of the pasting roll;
- the pressure exerted by the pasting roll.

The quality of pasting the layers obviously depends also on the quality of the used sheet. Even if it is a real hazard to recommend a set of optimal technological parameters for fabrication on SOLIDO SD 300 PRO device (even the producing firm did not dare this), as a result of the accomplished experimental researches, a set of optimal technological parameters is presented that may be used for the fabrication of the complex pieces on SOLIDO SD 300 PRO device.

From the accomplished experimental researches, there were deducted a few rules that are recommended to be considered when fabricating the models on SOLIDO SD 300 PRO device, namely:
- when loading the *STL file, we should accomplish a simulation of the sectioning, in order to prevent the problems that may appear due to the lack of certain faxes (deficiency connexions-STL files with flaws), or due to certain incorrectly defined objects;
- the platform astride should be accomplished after every one of its pre-instalment. The astride provides the platform horizontality and should be checked with calibrated rolls;
- at the beginning, we may work with a smaller speed of the pasting roll (ex.140mm/s), until the piece gets warm, and after that it is recommended the slight increase of the roll speed (to about160mm/s);
- after the first layers deposited in the piece, we may check (command Ctrl+P):

5. References
TEMPERATURE MONITORING WITH PROGRAMMABLE LOGIC DEVICES

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Abstract: The monitoring system is conceived as an open system which allows the later development (hardware and software) both in process and operating stations and the communication system level. The facilities of multiprocessing allow the later development of the system capacity without being affected its functioning. A monitoring also means the knowledge and the monitoring of the operation from the operator panel (HMI) of each equipment without moving from the place to see its unfunctionality [1].

Keywords: HMI – Human Machine Interface; PLC – Programmable Logic controller;

1. General considerations

The monitoring system based on equipments with a programmable logic is used to realize the automation functions in performance field. The reliable construction if the monitoring system made it to be used by users in hard conditions of operation and environment, for example, in the vicinity of power equipments.

The hardware standard technology, the modular projection and the facilities (capability) of high performance programs offer to the system the following features [1]:
- an easy use in assembly or connection;
- easy change (replacement) with modular blocks;
- adaptability to use different inputs and outputs of power and tension;
- easy installation of the modules, vibration resistant, that are easy introduced in drawers;
- easy programming by structured programs and by the use of sections of standard programs (function blocks);
- easy communication with other programmable automatons and computers by using internal processors or communication interfaces and LANs;

The automation plant also named automation system, together the technological and electrical plant from the main plant technology and with the exploitation personnel form the system of operative management.

The monitoring is structured by the following levels:
- local individual monitoring;
- a monitoring centralized from a control room.

The facilities of multi processing allow the later development of the system capacity without being affected its functioning. The monitoring functioning supposes the operator notifies of all the information necessary to the knowledge of managed process evolution and the decisions of manual intervention over the process, direct (by manual commands of on/off, closing/opening), or indirect (coupling/decoupling from automated or sequential functions, as well as commands: increase-decrease by automated control loops when they are in automatic mode, etc.). By these interventions there is realized the monitoring function [2].

The monitoring and supervision functions ensure [4]:
- the interface with the operator that is simple, intuitive and flexible;
- the graphic equipments physically installed whose there are associated a number of
properties;
- acoustics and signaling when the monitored value overpassed a preset threshold;
- the possibility to set two damage thresholds (preventive/emergency);
- the alarm will be maintained just to the moment when the triggering condition dissipated and/or the operator confirmed it.
- the process command could be realized by:
  - the data introduction from the keyboard in fields configured by the user;
  - mouse selection from the command menu;
  - mouse selection in the selection table for fields.
  - software configurable buttons and acted touch-screen or with the mouse.

HMI technology (Human Machine Interface) ensures the human-machine interface (local monitoring) not being necessary for the man to move to the desired equipment placed to tens or hundred meters [4].

The achievement on the operator panel (HMI) of the technological plant supposes the detailed knowledge of the equipments that will be hardware assembled as well as the communication way between them. On the operator panel (HMI) there could be displayed different windows from a technological plant that includes equipments (monitoring, functioning fans, pipes, furnaces, water tank, temperature monitoring, actuator, sensors, thermocouples, mechanical action systems, product recipe, etc.) to their alarms and damages.

The example below focuses on the local monitoring of a part from the plant of a technical treatment furnace that is its heating system.

The furnace heating is given by the step-down transformers of 24 Vac/4000A stress, providing several carbon composite resistance. The maintaining in parameters of a heating system is given by the thermal converter and pyrometers that are installed on sides of each zone.

To realize a monitoring system there are followed the next steps:

2. The hardware inclusion of field and command equipment. The field and command equipments are physically connected and the information providing to the operator panel or superior network (control room) is realized through a proper communication network (PROFIBUS or ETHERNET network). The configuration hardware system, is composed by [3,4]:
   - programmable automaton;
   - HMI operator panel;
   - Thermocouples;
   - Pyrometers;
   - Terminal box, they link the field elements and I/O digital and analogical modules;
   - Analogical inputs;
   - Communication network (ex. PROFIBUS).

3. Programming hardware plant. At the level of programmable automaton and operator panel HMI there are made the following operations:
   - graphical interface of the thermocouples and their control;
   - the achievement of the functioning logic of the thermocouples in process;
   - the communication achievement between the HMI panel and the programmable automaton.
The interface of field equipments on HMI panels is realized by a special soft named Win CC flexible, figure 1.

**Fig.1 The thermocouples and pyrometers distribution in a heating module realized by WinCC flexible**

On the operator panel there are displayed tags that go in a functioning logic from the programmable automaton. So, on the operator panel there are put the functioning parameters of the following equipments (thermocouples, thermal resistance, pyrometers,…etc), temperature diagrams, alarms and damages from the process ..etc.

Because of the different temperature bearings, the control of heating system is firstly made with thermocouples and after that there is used the heating control with pyrometers. In figure 1 there are monitored 10 parameters that measure the heat inside the module, thus:
- in the bottom and top side there are 4 thermal resistances (TT1501d...g; TT1601d...g) that measure the temperature to the module layer;
- to the left side there is located the thermocouple (TT901c) that measures the module isolation temperature;
- to right side there is located the pyrometer (TIT1601b) that measures the temperature inside the module form other heating bearing (cca 1200 C>).

In figure 2 there is presented the window of heating system of the furnace from the operator panel HMI during its functioning.

This window gives us the following measured data:
- “Insulation Temperature”;
- “Vessel Temperature”;
- “Vessel Temperature (Pyrometer)”;
To control the functioning of the heating resistance representative to the work area there are displayed the following data:

- resistance;
- resistance power;
- the current absorbed by the resistance;
- the heating system on “1 ON” position;
- the heating system on “0 OFF” POSITION;

Fig. 2 Temperature monitoring during the functioning

The functioning logic of the thermocouples is programmed in SLT logic (statement list) is the following, see figure 3 below [3].
Fig. 3 The functioning logic of field equipment

Also in Win CC flexible there is programmed a window to see the variation in time of the temperature and of those 4 parameters of the heating element (current, tension, resistance and power), see figure 4:

Fig. 4 Variation time of the 4 parameters heating element
4. Objectives
A system of **operative management** should ensure simultaneously management of the technological process and it should allow the exchange of information with the exterior to be as uniform as the achievement technique, operation and maintenance.

5. Conclusions
Therefore the solution of a **management system** should ensure:
- the safety increase in functioning of the plants, by avoiding the damages with effects over the personnel or equipments and the availability increase of production capacities;
- the insurance of inexpensive exploitation by obtaining low consumption, of several high yields and thus the obtaining of low production costs;
- the work conditions improvement by low operations volume that need physically effort and on this basis the qualification increase of operational staff;
- low necessity of routine activities, offering the possibility of minimizing of labor force implied in functioning activities, maintaining and administratice;
- a flexible communication concept that allows the access to all process data necessary to an operative management, a control system with programmable equipments that also allow the integration of different automation systems from different generations;
- the information transmitting to a controlling network;
- the system opening to allow subsequent developments.

References
EQUIDISTANT TOOTH GENERATION ON NONCYLINDRICAL SURFACES FOR TWO-PARAMETER GEARING

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National Technical University “Kharkov Polytechnic Institute”, Ukraine

Abstract: The questions of design research of noncylindrical tooth surfaces for two-parameter gearing on example of bevel gears with constant normal pitch for gearing variators are been considered. Engineering is based on the special applied development of the mathematical theory of multiparametric mappings of space.

Keywords: gear-shaping cutter, bevel gear, constant normal pitch, two-parameter gearing, gearing variator

1. Introduction

Certain results of researches and designs in the network of this approach supporting design research development of engineering and conversion for a full-scale realization of technical ideology of the two-parametertoothed variators with use of the noncylindrical gears with constant normal pitch [1, 2] are considered here.

Theoretical fundamentals of the two-parameter gears mesh and wheelworks based on the special gear wheels with constant normal pitch inclusive of variators are developed by Ukrainian Soviet scientist V.R.Kovalyuk and primarily were to develop of goods for special technics at the expense of overall advantages uppermost. Wheels with "equal-high-broad teeth and gashes" [1] have equidistant helix line of teeth which are situated at kinematic pitch surface of rotation of generating profile with variable radius of generatrix. Two-parameter character of gearing consist in independence of running-in parameters and alteration of wheel relative position. Equidistant toothspiral geometrically come out as result of implementation of dual one-parametric motion of particle: about axis of kinematic pitch surface and in the line of it generatrix [1].

Unified approach to theoretical and practical developments of objects, tools and processes of machining founded by B. A. Perepelitsa on multiparametric affine mappings of space [3] and accepted at the NTU “KhPI” Scientific and Technical School of Physics of Cutting Processes allows to consider different kinematical and geometric aspects and interactions over a period of product life cycle on the unified mathematical elemental platform.

Considered approach and experience of its consistent theoretical development [4, 5]; supporting by software [6] and generalization in the line of developing of theoretical bases of generation of unified multiparametric information for CAD/CAM systems of gearing, tools and gear processing [7-10] are identify oneself with trend dominance in industrially developed countries of world a so-called CALS-technologies associated with paradigm of use of interconnect information space (integrated infomedia) on the base of international standards for uniform information interaction of all participants of product life cycle: customers and suppliers, exploiting and maintenance personnel.

2. Model of shaping

Workable approach allows considerably simplify accounts and reduce of timetable formaking of geared variators of new generation about double- and three-link two-parameter transmission gears using advanced bevel or spherical gears with constant normal pitch (equidistant helix line of teeth).
The main difficulties of design and practical implementation of gear-shaping technologies of the two-parameter gears mesh and wheelworks based on the special gear wheels with constant normal pitchare tied with shape-generation complexity of noncylindrical gears. Comparative analysis of toothline placement on the bevel and spherical kinematic pitch surfaces (fig. 1) on example with similar geometrics (table 1) illustrate comparative comparatives of considered geometrical variants of noncylindrical gear:
- toothline on spherical kinematic pitch surface is more lengthy, and this disparity increases with increase of radius of lateral generatrix that make possible to change the angles of skew axes in greater range, and thereby it is possible to increase functionality of gear on the base of spherical wheels;
- mass of bevel wheel is less and so gears on the base of such wheels will be prime mass-overall data.

**Table 1:** Comparison macrocharacteristics of noncylindrical gear geometrical variants with equidistant helix line of teeth equal-tilted initially for initial work material with height of 60 mm, diameters of base and vertex of 80 mm and 40 mm, respectively

<table>
<thead>
<tr>
<th>Work material form</th>
<th>Length of lateral generatrix, mm</th>
<th>Length of tooth line, mm</th>
<th>Mass of steel block, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truncated cone</td>
<td>63.25</td>
<td>80.80</td>
<td>1.371</td>
</tr>
<tr>
<td>Layer of sphere</td>
<td>68.47</td>
<td>93.57</td>
<td>2.195</td>
</tr>
</tbody>
</table>

Unified technical approach [3, 8] can be used in simulation for research of gears with different degree of complexity. Three main forming methods in gear treatment we are marked out and investigated [10] with use of mathematical model generalizations [7, 9]. Model on principle of copying include two methodical variants of treatment, there are by generating line and tool surface; and model of revolving is based on point contact of gear-shaping tool and workpiece, in this connection machine and working gearing are completely identical. Here it will be considered in application to bevel gears, table 2.

Omitting here subsequent consideration of the first two models respectively supported on the use of pencil and disk shaping cutters (milling cutters) we will consider third scheme of shaping (table 2) remembering that permanent meshing of kinematics by rise of movement number is taken placed when conversion from the first to the third shaping method [10].

According to the third scheme of shaping a gear production is realized by revolving than with indexing movement such as by the first two schemes. In generalized structural formulation:

\[
\overrightarrow{r} = \varphi_2 u \overrightarrow{\beta} \overrightarrow{R}_1 + \varphi_1 \overrightarrow{\Psi} \overrightarrow{R}_2 + \varphi_1 \overrightarrow{\Psi} v u \overrightarrow{R}_2 .
\]

Tool makes additional turn \( \overrightarrow{\beta} \) and at the same time translational movement \( \overrightarrow{u} \) along pitch element which commits rotary \( \overrightarrow{\Psi} \) and reverse \( \varphi_1 \) motions about proper axis. Parameters of broadened matrix notation [9] are possessed the value: \( \varphi_1 = 0; \ m_{\varphi_1} = 1; \ \varphi_2 = 0; \ m_{\varphi_2} = 1 . \)
Table 2: Gear cutting technique for bevel gear wheels with constant normal pitch

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Copying (with dividing)</th>
<th>Running-in with a point contact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>by generating line</td>
<td>by tool surface</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kinematic scheme</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concise description</td>
<td>The tool is end-mill type gear cutter with shaped profile making linear motion along of conegenerating line, and conic workpiece makes rotary motion from independent drive</td>
<td>The tool is disk cutter with shaped profile making linear motion in the line of cone generating line, spinning motion and rotary motion of additional turn. Conic workpiece turns from independent drive</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The tool is gear shaper cutter or hone making running-in motion copying working gearing. Tool makes spinning motion, rotation about aworkpiece, rotary motion of additional turn and linear motion along of conegenerating line. Workpiece makes reversive axial rotation</td>
</tr>
</tbody>
</table>

Shaping by the first two methods does not reproduce the kinematics of real gearing in full, necessity of divider application is leading to accumulation of error on every next tooth. The first method (with point contact of tool surface) can be considered as scheme of preprocessing. The second one (with more accurate line shape-generating contact) can be used for making of gears with mean quality indexes. Examined here the third method excludes all listed shortcomings, but needs in high-value equipment. Realization of this processing technique by running-in method allows to obtain theoretically accurate tooth surface profiles and make bevel gears with high quality metrics. Model of forming by copying technique with dividing can be used on production for gears of average and low degree of accuracy or like preliminary, and model of forming by running-in technique can be used in treatment of gears with fine precision.

3. Software

At the NTU “KhPI” [9] it has been worked the complex of modules for execution of computing experiments and obtaining of visual images for verification of direct motions as inverse ones and characteristics of rounding which in the aggregate are accountable for accuracy of shaping of gearing.
Software of complex of modules for geometric simulation of objects, tools and processes of gear treating involute and noninvolute shaping based on their systematization and multiparametric mappings consist of application programs of detached judgment of particular tasks and the main program protective conformity of solutions of particular tasks, required compatibility of conditions of working and generating gearings.

The soft complex can be used at the different stage of life cycle for objects and tools of gear treatment (design, production, manufacturing and field inspection, culling). It is recommended for applicability checking calculation of serially producible tool in specific gear treating intents as well as for performing calculations and visualization of geometry of special purpose tool if standard tool application is found impossible.

Table 3: Calculating-graphic modules for simulation of detail (D), tool (T) and kinematics (K) in special gearing design

<table>
<thead>
<tr>
<th>Module</th>
<th>Object</th>
<th>Objective</th>
<th>Mathematical kernel</th>
<th>Development resource</th>
<th>Formalization of information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Involute</td>
<td>D</td>
<td>Calculation of tooth surface in normal section</td>
<td>Synthesis of known tooth shaping calculations in united complex</td>
<td>Delphi</td>
<td>Module, tooth number, gear-pitch angle, type of tooth surface, Graphics and table of 2D coordinate arrays</td>
</tr>
<tr>
<td>Profile</td>
<td>T</td>
<td>Calculation of tool profile in normal section</td>
<td>Own product on the base of theory of mappings</td>
<td>Fortran</td>
<td>Output information of Involute module, tool type and parameters, Table of 2D coordinate arrays of tool profile in normal section</td>
</tr>
<tr>
<td>Kromka (Edge)</td>
<td>T</td>
<td>Tool visualization</td>
<td>Developing of the Institute of Applied Mathematics of the Russian Academy of Science</td>
<td>Grafor</td>
<td>Output information of Profile module, Vector graphics</td>
</tr>
<tr>
<td>Helix</td>
<td>K</td>
<td>Calculation of equidistant tooth lengthwise curves</td>
<td>Own product on the base of theory of mappings</td>
<td>C++, Csape</td>
<td>Geometric and technical wheel parameters, Table of 3D coordinate arrays of tooth lengthwise curves</td>
</tr>
<tr>
<td>Spiral Surface</td>
<td>K</td>
<td>Vizualization of equidistant tooth lengthwise curves</td>
<td>Application of library of algorithmical language</td>
<td>C++, Csape</td>
<td>Output information of Helix module, Imagery of equidistant tooth lengthwise curves on kinematic pitch surface</td>
</tr>
<tr>
<td>Zub (Tooth)</td>
<td>D</td>
<td>Vizualization of tooth surface lengthwise of equidistant curves</td>
<td>Own product on the base of theory of mappings</td>
<td>Delphi</td>
<td>Output information of Helix, Kromka, Spiral Surface modules, Imagery of tooth surface on kinematic pitch surface</td>
</tr>
</tbody>
</table>

Complex (Table 3) is organized under principle of openness and may be completed by a new modules (programs) and internal modules (subprograms), as previously developed modules are exchanged for more perfect, and besides nonconflicting. This makes it possible to maximum efficiently operate whole complex when there are taken place improvement of certain calculated procedures and their completion, appropriate compliant software engineering.

General idea of realized in complex modular approaches to algorithmic and software-based solutions of gearing profiling tasks on the base of its tipification with use the system of unified parameters and space mappings specially adapted to shaping by cutting is belonged to prof. B.A. Perepelitsa [3, 7, 8].
Processing results of complex program modules are used for stocking of CAD/CAM databased library, as well as for analysis and decision-making in tabular and graphic forms.

4. Special purpose shaper tool

In fulfilled engineering of gear cutting tools for shaping of noninvolute gears with constant normal pitch it is provided for exclusion of distorted profiling after tool regrinds. There are proposed constructive approaches; procedure for estimate of influence of bevel gear’s with constant normal pitch shaping parameters on quality metrics of two-parameter toothed gearing [9]; generalized and particular calculation algorithms [10], which may be used in dataware of respective CAD/CAM systems of maintenance for tooling backup. Among developed tools there are assembled shaping cutters [10] with prismatic and round cutters. Compensatory possibilities of proposed assembled shaping cutters are ensured by repositioning of shaped cutting edges after their regrindings by linear displacement of prismatic shaper cutters and angular displacement round ones respectively.

5. Bevel gears in double- and three-link variators with two-parameter gearing

Thanks to constancy of normal pitch gearing with equidistant helix line of teeth have improved functional properties, serviceability and fabricability as compared with constructions of two-parameter gearings with variable module et al. [7]. In advanced industrial practical application in different branches such vary-drives make it possible to synthesize a new adaptive resource-saving compact mechanisms and machines. Transformation of double-link two-parameter gearing on the base of bevel gear with constant normal pitch in tooth variable speed unit with variable (regulable) gear-contact ratio is made [2] by imposition of compound wheel in place of affiliate disk wheel with narrow gear ring (fig. 2).

Three-link cylinder-conic gear variators working with double complementary use of the same principle of controlled displacement of movable teeth of spur gear are completed by two such spur gears and central bevel gear with constant normal pitch of teeth.

Bevel gears with equidistant helix line of teeth also [2] are pair entities of interaction with central gear in a form of spherical layer with constant normal pitch of teeth (fig. 1b) in three-link sphero-conical advanced variators.
6. Conclusions
Work executed with any given design accuracy allows to implement a design of tool and technologies of bevel gear forming with equidistant helix line of teeth including for special gear variators; as well as to achieve of labor saving, rise of level of theoretical justification and effectiveness in solution of current engineering tasks.

References
DETERMINATION OF THE SIZE OF BLANK NECESSARY TO OBTAIN A DEEP DRAWING USING SOLIDWORKS

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Abstract: The development of the approximate blank size should be done to determine the size of a blank to produce the shell to the required depth and to determine how many draws will be necessary to produce the shell. This is determined by the ratio of the blank size to the shell size. Various methods have been developed to determine the size of blanks for drawn shells. These methods are based on algebraic calculations; the use of graphical layouts; a combination of graphical layouts and mathematics.

Key words: deep drawing, solidworks, blank

1. Introduction

In deep drawing the sheet (the blank) is put on the die, which possesses the shape of the product to be drawn. Then the blankholder is closed on that part of the sheet, which is not deformed by the punch. The blankholder prevents wrinkling of the sheet and controls the sliding of the sheet during the drawing process. After closing the blankholder, the punch is moved downwards deforming the sheet to its final shape.

The process of deep drawing a cylindrical cup is schematically shown in Fig. 1. This shows the successive steps from an originally flat rolled sheet (which is also called the blank) to the product with its final shape. The first step consists of the application of the lubricant on the sheet. The second step is the closure of the blankholder. The force, which is applied to close the blankholder is called the blankholder force $F_{bl}$. The third step is the actual drawing process itself.

![Fig. 1. The process of deep drawing a cylindrical cup.](image)

2. Blank development for cylindrical shells

Development of Blanks. The development of the approximate blank size should be done to determine the size of a blank to produce the shell to the required depth and to determine how many draws will be necessary to produce the shell.

This is determined by the ratio of the blank size to the shell size.

Various methods have been developed to determine the size of blanks for drawn shells.
These methods are based on algebraic calculations; the use of graphical layouts; a combination of graphical layouts and mathematics. The majority of these methods are for use on symmetrical shells.

It is rarely possible to compute any blank size to close accuracy or maintain perfectly uniform height of shells in production, because the thickening and thinning of the wall varies with the completeness of annealing.

The height of ironed shells changes with commercial variations in sheet thickness, and the top edge differs from square to irregular, usually with four more or less pronounced high spots resulting from the effect of the direction on the crystalline structure of the metal. Thorough annealing should largely remove the directional effect.

For all these reasons, it is usually necessary to figure the blank sufficiently large to permit a trimming operation.

The drawing tools should be made first, then the blank size should be determined by trial before the blanking die is made.

There are times, however, when the metal required to produce the product is not immediately available from stock and must be ordered at the same time as the tools.

This situation makes it necessary to estimate the blank size as closely as possible algebraically or graphically to know what sizes to order.

**Algebraic Method** is schematically shown in Fig. 2. The following equations may be used to calculate the blank size for cylindrical shells of relatively thin metal. The ratio of the shell diameter to the corner radius can affect the blank diameter and should be taken into consideration.

$$ S_{semif} = \frac{\pi D^2}{4} = S_{piewa} = s_1 + s_2 + \ldots + s_n + s_a = \sum_{i=1}^{n} s_i + s_a \quad (1) $$

$$ D = 1.13 \sqrt{s_a + \sum s_i} \quad (2) $$

Where $s_i$ it is areas of simple elements in which the dish piece was break down, and $s_a$ – area, co-appropriate addition of cutting edge necessary.
**Layout Method** (fig. 3). The procedure to determine the blank is as follows:
1. Make an accurate layout of the part, including a line through the center of the stock.
2. Number each dissimilar section starting at the extreme edge of the part.
3. Draw vertical line X-Y and mark off the length of each section accurately starting with section I at the top of the line. Number each section to correspond with the same section of the shell.
4. Through the center of gravity of each section, draw a line downward parallel to line X-Y. The center of gravity of an arc lies on a line which is perpendicular to and bisects the chord and is two-thirds of the distance from the chord to the arc.
5. From point X draw line A at 45° to point P, which is about midway between X and Y. Draw line A' parallel to line /I intersecting the lines drawn in step 4.
6. Connect P to the ends of the sections on line X-Y obtaining lines B, C, D, and E. Draw parallel lines B' C’ D’ and E’. Note that B’ starts where A’ intersects the first center-of-gravity line and so on until where E’ intersects the fourth center-of-gravity line and continues to intersect A’.
7. Through the intersection of A’ and E’ draw a horizontal line Z to the center line of the shell. Construct a circle using Y as the center point and Z as the diameter. Using point X as the center point, scribe an arc tangent to the small circle.
8. Draw a horizontal line tangent to the top of the small circle until it intersects the large arc. The distance from this intersection to line X — Y is the radius of the required blank.

![Diagram](image-url)

**Fig. 3.** *Determining the blank size by the area-of-elements method.*

3. **Determination the size of blank necessary to obtain a deep drawing using solidworks**
   The method consists in going through several steps:
   First, we draw a geometric shape and generator parts to share data using the submenu "Sketch" (Fig. 4)
Fig. 4. Draw the geometrical shape of the generating part and share data using Sketch submenu.

The model generated using the submenu "Future" and command "Revolve" (fig. 5).

Fig. 5. Generate the model using the submenu "Future" and on the "Revolve"
Volume is calculated using submenu "Evaluate" command "Mass Properties" (fig. 6).
Fig. 6. Calculation of volume using submenu "Evaluate" command "Mass Properties"
In this example to calculate the diameter of the blank part volume equals the product of area and thickness of the blank as follows:

\[ A = V / g = \frac{39963.17}{1} = 39963.17 \text{mm}^2 \]  

(3)

where:

- \( A \) - blank area;
- \( V \) - part volume;
- \( g \) - thickness

\[ A = \frac{\pi D^2}{4} = 39963.17 \text{mm}^2 \]  

(4)

\[ D = 225.63 \text{mm} \]

4. Conclusions:

By the method of finding the appropriate size blank dish piece use SolidWorks software simplifies the mathematical calculations and also reduce the time required in respect thereof.

New method has the advantage that parts can be applied regardless dish pieces their geometric complexity.

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RELIABILITY OF LENTICULAR EXPANSION COMPENSATORS

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Abstract: Axial lenticular compensators are made to take over the longitudinal heat expansion, shock, vibration and noise, made elastic connections for piping systems. In order to have a long life for installations it is necessary that all elements, including lenticular compensators, have a good reliability. This desire can be did by technology of manufactoring and assembly of compensators, the material for lenses and by maintenance of compensator

Keywords: reliability, maintenance, lenticular compensators, life cycles, lens, technology

1. Introduction

In the energy industry, chemical, petrochemical, aerospace, food, mining and agriculture, they handled significant quantities of fluids, pressures and high temperatures.

The transport of these fluids is characterized by large values of working parameters and long distances. They require piping systems which is the technical solution required to take over the pipeline length variations.

Variations in length of the pipeline are due to the negative influence of low temperatures (-160 °C) or high temperatures (600 °C) of the circulating fluid and the ambient temperature in which installations must operate.

To avoid damage or even destruction of facilities (cracking of welded joints of pipe and pipe elements, leakage, loss, so on) due to changes in length, dilation thermal compensation systems were conducted, as follows:

(i) expansion pounds U, L or Z;

(ii) compensating sliding telescopic expansion (Fig. 1);

(iii) compensating expansion with spherical articulations (Fig. 2);

Fig. 1. Compensating sliding telescopic expansion
Fig. 2. Compensating expansion with spherical articulations

(i) expansion compensators lenticular (Fig. 3).

Fig. 3. Expansion compensators lenticular

Expansion pounds are used to acquire thermal dilations of the ducts which operate at relatively low pressures and fluid temperatures, assuming only axial expansions of pipelines.

Telescopic sliding expansion compensators are generally avoided to be used due to their low reliability, caused by rapid degradation of the sealing system seals.

To increase the reliability of such an activity, it is necessary a compensating preventive maintenance (greasing continuous) or corrective maintenance (replacement) of gaskets, an activity which is quite hard.

Expansion compensators with ball joints are also used quite limited, because they can retrieve only the plane perpendicular to their axis (Fig. 2) and the tightness is not good enough in order to prevent fluid losses.

Reliability spherical sealing is low, leading to an overall low reliability of the compensator.

2. Reliability of lenticular expansion compensators

2.1. General presentation

Lenticular expansion compensators are mostly used to acquire thermal dilations of pipelines, first of all due to their high reliability and their perfect tightness. It may also cover different areas: acquiring thermal expansion, shock absorber and vibration, make connection elastic piping systems.

The main element of this type of compensator is the lenticular (lens, bellows, tears) that must be executed correctly, to have a geometry very well studied, to having theirs sudden changes of direction in section thickness or profile.
In general, the lenses are simple circular or toroidal elements that are welded, of which the welding process is done either by hand or electric welding in protective gas medium (WIG-Wolfram, Inert, Gas):

(i) circumferential (Fig. 4);

(ii) longitudinal (Fig. 5).

Reliability of lenticular compensators expansion is influenced by the following:
(i) the reliability of the lens (geometric shape, technology implementation, material fabrication);
(ii) execution quality welds, transverse and longitudinal;
(iii) preventive maintenance work, applied during the operation of pipeline systems.

Lenticular expansion compensator can be considered as a set of three elements, the lens barrel stacks and flat flanges or necks, elements connected in series through the circular welding seams (Fig. 6).

2.2. Experimental research on the reliability of expansion compensators lenticular

Reliability compensator $R_c(t)$ is given by the product reliability of components, the lens $R_l$, $R_{pipe}$, flange $R_{flange}$ as the relationship we have known for components connected in series:

$$ R(t) = \prod_{i=1}^{n} R_i(t) $$

or

$$ R_c = R_l R_{pipe} R_{flange} $$
Note: It is the working assumption that the mechanical strength of circular and longitudinal welds is equal to that of other components. Compensator is necessary for reliability and hence reliability $R_{lenticular}$ elastic element is greater than the minimum allowable reliability required by the user for an industrial installation in which it is mounted.

**Reliability** of lenticular compensators expansion depends on:

1. the number and nature of fatigue load cycles;
2. material quality and lenticular elements;
3. the working fluid, pressure and temperature;
4. lens geometry (shape, wall thickness, step height);
5. chemical aggressiveness of the working fluid;
6. the ratio between the number of lenses and their diameter;
7. manufacturing technology of the lens (longitudinal, seam or seam circular) and mounting technology of compensators components (flanges, pipe, elastic elements).

### 2.2.1. Influence of fatigue load cycles on the reliability of compensators

Principal application: submitted compensator, the entire life cycle is due to the load of cyclic compression and tension.

Lenticular compensators is the main failure crack in the wall of the lens that appears after a variable number of cycles of demand, determined by observing the behavior of the compensator during installation or operation of laboratory tests.

There have been laboratory tests under conditions of axial compression and tension compensating lenticular, various diameters, $D_n=150, 200, 300, 400, 450$, with a total of three lenses each, and lens thickness $s=2$ mm. Material fabrication was austenitic stainless steel sheet, obtaining the results in Table 1.

Alternating cycles were symmetrical and pulse.

Tensile strength for a pulsating cycle is greater than that for a symmetrical alternating cycle:

$$\sigma_0 = 1.5 \sigma_1$$  \hspace{1cm} (3)

Tensions introduced into the material, which caused by the tensile cracking and breaking, the lens is not only the mechanical but also thermal in nature. Thus, the austenitic stainless steel which runs lens compensators, thermal tensile stress is a major show, because these materials have low thermal conductivity and high thermal expansion.

### Table 1: Test compensator storequest periodic variables

<table>
<thead>
<tr>
<th>No.</th>
<th>$D_n$</th>
<th>$\delta_1$ displacement lens (mm)</th>
<th>$\delta$ displacement total (mm)</th>
<th>nature cycles</th>
<th>$N$ number cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>150</td>
<td>3.5</td>
<td>10.5</td>
<td>$\sigma_1$</td>
<td>2340</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>3.5</td>
<td>10.5</td>
<td>$\sigma_0$</td>
<td>4560</td>
</tr>
<tr>
<td>3</td>
<td>300</td>
<td>3.5</td>
<td>10.5</td>
<td>$\sigma_1$</td>
<td>2620</td>
</tr>
<tr>
<td>4</td>
<td>400</td>
<td>3</td>
<td>9</td>
<td>$\sigma_1$</td>
<td>2560</td>
</tr>
<tr>
<td>5</td>
<td>450</td>
<td>5</td>
<td>15</td>
<td>$\sigma_1$</td>
<td>2480</td>
</tr>
</tbody>
</table>
The fatigue behavior of lenticular compensators expansion is determined by factors:

(i) the maximum tension applied;
(ii) large variation of the applied tension;
(iii) a high number of cycles;
(iv) the concentration of tension;
(v) the corrosive effects of the working fluid;
(vi) the working fluid temperature;
(vii) residual stresses from materials used in the implementation of lenses, flanges and pipes.

Fig. 7 presents the cycle of tension varying effects produced in points 1, 2, 3, 4 expansion compensator lens surface with Dn=300.

The diagram shows that the greatest tension is developed at the base and top lenses (points 1 and 4). The value of the tension drops to half the area of the lens attachment (2 or 3 points), so that the right portion of the lens wall is almost negligible.

Crack initiation and rupture occur in most cases at the base and the tip of the lens. If rupture occurs in other areas, it is due to hidden defects in the material, which can facilitate the production of cracks (pores, inclusions, improper structure).

2.2.2. The influence of technology on the reliability of manufacturing and assembly of compensators

The most advanced manufacturing process (implementation and control) is the elastic elements of the semi-mechanical deformation of austenitic stainless steel sheet, followed by special rolls production having required geometry. Welding is made by welding the longitudinal ends by the process of manual or electric atmosphere of protective gases non-fusible electrode (WIG, Wolfram Inert Gas).

To increase the compensators reliability is important that the montage of elements to be made of welded joint pipe, which can be butt weld or corner weld (Fig. 8).
For the connection by welding, butt welding is preferable (Fig. 8. a) to weld the corner (Fig. 8. b). Weld seam for butt welding quality is equal to the mechanical strength of the base material and a tight seal. This type of compensators does not require special supervision, and their maintenance is minor.

In Fig. 9. a, b, c are listed constructive measures to be taken in order to make minor maintenance: protection pipe inside the elastic element (Fig. 9. a), caps applied to the bottom of the lense to eliminate condensation (Fig. 9. b) protective sleeve on the outside of the elastic element (Fig. 9. c).

![Fig. 9.](image)

2.2.3. Influence of the reliability of maintenance compensators

Remedy by gouging (removing defects by local melting of the material and its removal with a jet of compressed air) of cracks in the walls of the lense or cords, welding and grinding addition of material. Repairs carried out in such permit to extend the life of the lenticular compensators average value of the number of cycles that occurred before the emergence of the first failure, i.e. until the first occurrence of cracks.

Arrival of the first cracks in the elastic elements (lenses) are not automatically determine the disposal of compensators.

References

THE MATHEMATICAL MODEL OF CLARIFYING PROCESSES FOR INDUSTRIAL WASTEWATERS

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Abstract: To minimize the SS amounts in the effluent from the settling tanks, SS predictive methods are needed. By applying mathematical models, it is possible to predict the SS concentration from the settling tank; the predictions can be used in order to choose the best control action, that is whether changing the flow path is needed or not whether changing the flow path is needed or not; whether mixing caused by the sludge removal from the tank should be stopped or limited. From the presented model, as well as from the graph of Gauss bell, we notice that the SS concentrations in the effluent from the settling tanks grow from m to m+3T/(x-m/3T); i.e. the SS concentrations in the effluent from the settling tanks are Gaussian.

Keywords: mathematical model, clarifying processes, wastewaters

1. Introduction

Two layer model of settling in a sludge settling tank. The two layer model of sludge settling in a tank is:

\[ X_s = \frac{d_s}{d_s - d_w} \cdot X_w \]

Fig. 1. The mathematical model of clarifying processes for industrial Wastewaters.

When the flow is stopped, the suspended solids settle. The water in the layer above the sludge blanket is assumed to be clear water, and the layer under the sludge blanket is assumed to contain all the SS fully mixed (in tank 1 the solution for the (α) – convex differential equation (12) and in tank 2 the solution of the(β) – convex differential equation (13).

The settling velocity is modelled according to veselind [1] according to the differential equation:

\[ \frac{dd_{sb}}{dt} = V_0 e^{-n_s X_{ssl}} \] (1)

where \( d_{sb} \) denotes the sludge blanket depth, \( X_{ssl} \) is the SS concentration in the sludge layer (fig. 1) and \( V_0 \) and \( n_v \) are sludge volume index (SVI) dependent parameters. For simplicity, we use the expressions found by Härtel and Pöpel (1992)

\[ V_0 = (17.4e^{-0.01135SVI} + 3.931) \]

\[ n_v = (-0.9834e^{-0.00581SVI} + 1.043) \] (2)

As the volume of the sludge layer is \( \frac{(d_{ub} - d_{sb})W}{d_{ub}} \) the average SS concentration in the sludge layer is:
where $X_{ssm}$ is the average SS concentration in the tank.

When the tank is fully mixed, the sludge blanket depth is $d_{sb} = 0$.

The following differential equation:

$$\frac{dd_{sb}}{dt} = -\frac{1}{\tau_{mix}} d_{sb}$$  \hspace{1cm} (4)

show that when the flow is continuous, $d_{sb} \to 0$ ($d_{sb} = C \cdot e^{-\frac{t}{\tau_{mix}}}$) where $\tau_{mix}$ is a mixing capacity dependent time constant.

With $m_1$ and $m_2$ denoting the mixing signals for settling tank 1 and 2 respectively. The mixing signal is 1 when the corresponding tank 1 is mixed and 0 otherwise.

The signals can then be used to combine the settling equation (1) with the mixing equation (4).

We get for each of the two tanks, two ($\alpha$) differential equations and ($\beta$) convex, respectively for each of the two sludge settling tanks.

\[
\frac{dd_{sb1}}{dt} = l(m_1)(-\frac{1}{\tau_{mix}} d_{sb1}) + (1 - l(m_1))V_1 e^{-n_{u1}} X_{ss}\]

\[
\frac{dd_{sb2}}{dt} = l(m_2)(-\frac{1}{\tau_{mix}} d_{sb2}) + (1 - l(m_2))V_2 e^{-n_{u2}} X_{ss}\]

where $d_{sb1}$, $d_{sb2}$ = the sludge blanket depths

$X_{ss1}$, $X_{ss2}$ = SS concentrations in the sludge settling tank 1 & 2 respectively.

The S.S. concentrations in the effluent from a sludge settling tank is modeled as a function of the suction depth, $d_{suct}$ and the SS concentration in the sludge layer $x_{ss}$:

\[
X_{ssout} = \begin{cases} 
\frac{d_{suct} - d_{sb}}{d_{suct}} \cdot X_{ss}\ & \text{for} \ d_{suct} \geq d_{sb} \\
0 \ & \text{for} \ d_{suct} < d_{sb} 
\end{cases}
\]

(7)

The suction depth is expected to depend on the flow and is modeled as:

$$d_{suct} = d_0 \left( \frac{Q + Q_o}{Q_o} \right)^{b_{suct}}$$  \hspace{1cm} (8)

where $d_0$ and $b_{suct}$ are positive parameters and $Q_0 = 1000 \text{ m}^3 / \text{h}$. Combining (3) and (7) we have:

\[
X_{ssout} = \frac{d_{suct} - d_{sb}}{d_{suct}} \cdot \frac{d_{at} - d_{sb}}{d_{at}} \cdot X_{ssm} = \frac{1 - \frac{d_{sb}}{d_{at}}}{1 - \frac{d_{sb}}{d_{suct}}} \cdot X_{ssm} \ & \text{for} \ d_{suct} > d_{sb}
\]

(9)

To study $X_{ssout}$ when the point $d_{suct} = d_{sb}$ we introduce a function which we will call logistic function.

Here, the logistic function:

$$l(x) = l(x,a,b) = \frac{1}{1 + e^{-\frac{a - x}{b}}}$$

is used.

For $x = a$, $l(a) = 0.5$. In the below figure we done $e(x)$ for $b \in \{0.2; 1.0; 2.0\}$ and $a = 0.$
The logistic function (10) is used to calculate $x_{\text{ssoutat}}$ while the flow path variable is used to select the discharge tank.

$$X_{\text{ssoutat}} = f_p \left( l(d_{\text{suc}} - d_{\text{sh}}) \right) \left( \frac{1 - d_{\text{sh}} / d_{\text{suc}}} {1 - d_{\text{sh}} / d_{\text{at}}} \cdot X_{\text{ssoutat}} \right) + (1 - f_p) \left( l(d_{\text{suc}} - d_{\text{sh}}) \right) \left( \frac{1 - d_{\text{sh}} / d_{\text{suc}}} {1 - d_{\text{sh}} / d_{\text{at}}} \cdot X_{\text{ssoutat}} \right)$$ \hspace{1cm} (11)

As $d_{\text{suc}}$ is only dependent on the flow, there is no need to consider different suction depths for each of the sludge settling tanks.

2. Matrix form

In order to use a matrix notation, we introduce the state vector $X$, the input vector $U$ and the observation vector $Y$.

$$X = [X_1, X_2, d_{sh1}, d_{sh2}]$$
$$U = [f_p, m_1, m_2, X_{at}, Q, Q]$$
$$Y = [X_1, X_2, X_{ssoutat}]$$ \hspace{1cm} (12)

By use of the vector function $f(X, U, t)$, the mass balances and sludge blanket depth equations can be expressed in an „a-convex” vector differential ($a = \alpha$ sau $a = \beta$) modeled as:

$$\frac{dX(t)}{dt} = f(X, U, t)$$ \hspace{1cm} (13)

where $f(X, U, t)$ is constructed from equations (1) – (13) and denotations (12).

The measurements are described by the observation equation:

$$Y(t) = h(X, U, t)$$ \hspace{1cm} (14)

where $h(X, U, t)$ is constructed from equations 11 and notations 12.

To count in uncertainties in the model formulation and to enable use of the maximum likelihood parameter estimation method, stochastic noise terms are introduced. Hence, the „a-convex” equation ($a = \alpha$ sau $a = \beta$) (13) turns an „a-convex” differential equation ($a = \alpha$ sau $a = \beta$) where the time equations describing the mass balances and the sludge blanket depths in the sludge settling tanks can be written as the no called differential equation „a-convex” (Oksendal, 1995).

$$dX(t) = f(X, U, t)dt + G(X, U, t)dw(t) = \left( \prod_{i=1}^{N} p(Y(t)/Y(t-1), \theta) p(Y(0)/\theta) \right)$$ \hspace{1cm} (15)
Where the stochastic process \( w(t) \) is assumed to be a standard vector Wiener process [5]. The function \( G(X,U,t) \) describes any state, input or time dependent variation related to now the variation generated by the Wiener process enters the system.

Here \( G(X,U,t) \) is assumed to be a constant diagonal matrix.

\[
G(X,U,t) = \begin{bmatrix} \sigma_x & 0 & 0 & 0 \\ 0 & \sigma_x & 0 & 0 \\ 0 & 0 & \sigma_y & 0 \\ 0 & 0 & 0 & \sigma_y \end{bmatrix}
\]  

(16)

The covariance of \( G \) \( dw(t) \) becomes

\[
\sum = GG^T = \begin{bmatrix} \sigma_x^2 & 0 & 0 & 0 \\ 0 & \sigma_x^2 & 0 & 0 \\ 0 & 0 & \sigma_y^2 & 0 \\ 0 & 0 & 0 & \sigma_y^2 \end{bmatrix}
\]  

(17)

The observation uncertainties are included in the observation equation

\[
Y(t) = h(X,U,t) + e(t)
\]  

(18)

where the term \( e(t) \) is the measurement error, which is assumed to be a zero mean Gaussian white noise independent of \( w(t) \) and with covariance matrix:

\[
V(e(t)) = \begin{bmatrix} \sigma_e^2(t) & 0 \\ 0 & \sigma_e^2(t) \end{bmatrix}
\]  

(19)

3. Estimation models

The method used to estimate the parameters of the model (15), (16), (18) is a maximum likelihood method for estimating parameters in stochastic differential equations based on information in different times given by the observation equation [1].

All the unknown parameters, denoted by the vector \( \theta \), are embedded in the continuous discrete time state model (15) and (17).

The measurements are given in discrete time, and, in order to simplify the notation, it is assumed that the time index \( T \) belongs to the set \( \{0,1,2,\ldots,N\} \) where \( N \) is the number of observations. Introducing:

\[
Y(t) = [Y(t),Y(t-1),\ldots,Y(1),Y(0)]'
\]  

(20)

where \( y(t) \) is a vector containing all the observations up to and including time \( T, T\ldots\{0,1,2,\ldots,N\} \) the likelihood function is the joint probability density of all the observations, assuming that the parameters are known:

\[
L'(\theta,Y(N)) = p(Y(N)/\theta) = p(Y(N)/Y(N-1),\theta)p(Y(N-1)/\theta) = \\
= \prod_{t=1}^{N} p(Y(t)/Y(t-1),\theta)p(Y(t)/\theta)
\]  

(21)

where successive applications of the rule \( P(A \cap B) = P(A/B) \cdot P(B) \) are used to express the likelihood function as a product of conditional densities. In order to evaluate the likelihood function it is assumed that all the conditional densities are Gaussian. In the case of a linear state space model, it is easily shown that the conditional densities actually are Gaussian [13].

In a non-linear case, as described by (15) and (17) the Gaussian assumption is an approximation.

The Gaussian distribution is completely characterized by the mean and covariance. Hence, to parameterize the conditional densities in (21), we introduce the conditional mean and the conditional covariance as
\[ \dot{Y}(t/t-1) = E[Y(t)/Y(t-1), \theta] \text{ and } R(t/t-1) = V[Y(t)/Y(t-1), \theta] \] (22)

It should be mentioned that these correspond to the one step prediction and the associated covariance, respectively. Furthermore it is convenient to introduce the one step prediction error
\[ \varepsilon(t) = Y(t) - \hat{Y}(t/t-1) \] (23)

The conditional likelihood function (conditioned or \( Y(0) \)) becomes
\[ L(\theta, Y(N)) = \prod_{t=1}^{N} ((2\pi)^{-m/2} \det R(t/t-1))^{-1/2} \cdot \exp\left(-\frac{1}{2} \varepsilon(t)^T R(t/t-1)^{-1} \varepsilon(t) \right) \] (24)

where \( m \) is the conditional likelihood function is given by the following relation:
\[ \log L(\theta, Y(N)) = -\frac{1}{2} \sum_{t=1}^{N} \log \det R(t/t-1) + \varepsilon(t)^T R(t/t-1)^{-1} \varepsilon(t) + \text{const} \] (25)

maximum likelihood estimate (ML-estimate) is the set \( \hat{\theta} \), which maximizes the likelihood function. Since it is not, in general, possible to optimize the likelihood function, a numerical method has to be used. A reasonable method is the quasi-Newton method.

An estimate of the uncertainty of the parameters is obtained by the fact that the ML-estimator is normally distributed with mean \( \theta \) and covariance
\[ D = H^{-1} \] (26)

where the matrix \( H \) is given by
\[ \{h_{ik}\} = -E\left[ \frac{\partial^2}{\partial \theta_i \partial \theta_k} \log L(\theta, Y(N)) \right] \] (27)

An estimate of \( D \) is obtained by equating the observed value with its expectation and applying
\[ \{h_{ik}\} \approx -E\left( \frac{\partial^2}{\partial \theta_i \partial \theta_k} \log L(\theta, Y(N)) \right)_{\hat{\theta}, \hat{\phi}} \] (28)

The above equation can be used for estimating the variances of the parameter estimates. The variance serves as a basis for calculating t-test values, for tests under the hypothesis that the parameter is equal to zero. Finally, the correlation between the parameter, estimates is readily found based on the covariance matrix \( D \) from (26).

4. Conclusions
- A two layer model of settling in a settling tank has been established, by using settling and mixing differential equations and concluding that when the tank is fully mixed, there is no sludge blanket, and when the flow is continuous, the sludge blanket depth tends to zero.
- Further mixing signals \( m_1 \) and \( m_2 \) of settling tanks 1 and 2 have been used, combined with mixing and settling equations, to establish the SS concentration in the sludge layer from tank 1 and 2.
- The SS concentration in the effluent from the settling tanks has been established, depending on the suction depth and on the SS concentration in the sludge layer by using the logistic function \( l(x) = l(x,a,b) \) – where from we can conclude that the suction depth only depends on the flow, so there haven’t been considered different suction depths for each of the suction tanks.
- The study of the flow process, obtained from „a-convexity” has been processed in a computer programme. By processing the information, different values of \( \alpha \in [0,1] \) and \( \beta \)
$\in [0,1]$ have been obtained as well as different values of the sludge blanket depth $d_{sb1}$ and $d_{sb2}$.

- The results from the elaborated programme have been interpreted as discrete likely variables. By using $x$ likely variable, a likelihood study and a maximum likelihood one of the modelled process, have been established.

- We have calculated the mathematical expectation, denoted by $m$ and the mathematical dispersal denoted by $\sigma$, and by using $\alpha$-convex and $\beta$-convex equations presented in the model, we obtained the values $m_\alpha$, $m_\beta$, $\sigma_\alpha$, $\sigma_\beta$. By using $m$ and $\sigma$ we designated Laplace – Gauss curve.

- Gauss’ bell helped us establish the SS concentrations ($X_{ssoutat}$) in the effluent from the settling tanks (the maximum values). Thus, it is noticed that $X_{ssoutat} = m$ is maximum point of $n(x,m,\sigma)$ its maximum value being $\frac{1}{\sigma \sqrt{2\pi}}$.

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AIR QUALITY AFFECTED BY INDUSTRIAL ACTIVITIES GORJ COUNTY, IN THE YEAR 2010

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Abstract: The paper presents the main industrial activities pollution the air, at the level of Gorj County, in the year 2010. There are mentioned gases with greenhouse effect, acid effect gases, their graphical representation and pollution produced by the main polluting agents of the county: depositing dusts and dusts in suspension.

Keywords: acid, emissions, atmosphere

1. Natural frame and the social – economic development of Gorj county

Situated in the south – eastern part of Romania, crossed by the middle course of Jiu and by parallel 45, north latitude, Gorj County, represents a real standard of diversity and harmony (figure 1.). It has a surface of 56,0174 ha and is bordered in the northern part by county Hunedoara, in the north – west by Caraş-Severin county, in the south – east by Dolj county, in the east by Valcea county, and in the south west by Mehedinţi county.

The main industrial activities contributing to the air pollution [1] in Gorj county are:
- Coal (lignite) exploitation as part of exploitations from Rovinari, Motru, Jîlţ
- Extraction of petroleum and natural gases in the areas Hurezani, Țicleni
- Electricity production in steam power plants from Turceni and Rovinari
- Electricity production in hydropower plants (on rivers: Jiu, Oltet);
- Wood exploitation and processing (timber, furniture, parquet, wood chipboard)
- Manufacturing of technical articles from rubber
- Machines manufacturing, mining equipments (Tg-Jiu, Rovinari, Motru)
- Manufacturing of housekeeping glass (Tg-Jiu)
- Food industry (bread manufacture, drinks, cigarettes)
- ranches
- confections

Fig.1. Gorj county map
2. Air’s quality evaluation in Gorj county, in the year 2010

2.1. Gases with greenhouse effect

The quantities of gases with greenhouse effect, released in Gorj county, in the year 2010 are presented in chart 1.

Table 1. The gases with greenhouse effect, released in Gorj county, in the year 2010

<table>
<thead>
<tr>
<th>Issuing activities greenhouse gas</th>
<th>CO₂(mii t)</th>
<th>CH₄(t)</th>
<th>N₂O(t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustion in energy and transformation industries</td>
<td>12344.52</td>
<td>397.10</td>
<td>855.64</td>
</tr>
<tr>
<td>In non-industrial combustion plants</td>
<td>1041.62</td>
<td>1384.92</td>
<td>70.01</td>
</tr>
<tr>
<td>Combustion in manufacturing industry</td>
<td>104.76</td>
<td>63.35</td>
<td>7.08</td>
</tr>
<tr>
<td>Productin processes</td>
<td>0.08</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Fossil fuel extraction and distribution</td>
<td>0.05</td>
<td>22142.51</td>
<td>-</td>
</tr>
<tr>
<td>Road</td>
<td>151.43</td>
<td>25.26</td>
<td>5.09</td>
</tr>
<tr>
<td>Other mobile sources and machinery</td>
<td>-</td>
<td>3.76</td>
<td>27.90</td>
</tr>
<tr>
<td>Treatment and waste disposal</td>
<td>0.84</td>
<td>3.66</td>
<td>-</td>
</tr>
<tr>
<td>Agriculture</td>
<td>-</td>
<td>9952.94</td>
<td>188.49</td>
</tr>
<tr>
<td>Other sources</td>
<td>-</td>
<td>-</td>
<td>539.74</td>
</tr>
<tr>
<td>Total</td>
<td>1364.31</td>
<td>33973.51</td>
<td>169.94</td>
</tr>
</tbody>
</table>

The quantities of carbon dioxide represent rough emissions [2]. The anthropic activities with the most important ponderosity in generating gases with greenhouse effect are combustion processes, in county Gorj functioning the two energetic systems of great power, C.E. Turceni and C.E. Rovinari. The CO₂ emissions appeared from combustion in energetic and transforming energies, represent 90% from the total of CO₂ emissions, forecast at county level and are presented in figure 2:

![Fig.2. Variation of CO₂ in the county Gorj in 2005-2010](image-url)
2.2. Acid forming process

The acid forming process is the one of modification of the natural thermal character of an environmental exponent, as a result of the presence of some compounds determining a series of chemical reaction in the atmosphere. The atmospheric emissions of the acid forming substances SO2 and NOx resulted mainly from fossil fuels combustion, can persist in the atmosphere for several days and can be transported at thousands of km, where the process of conversion into acids takes place (sulphuric and azothic). The emission of gases with acid forming effect evaluated for the year 2010 are presented in chart 2.

**Table 2. The emission of gases with acid forming effect evaluated for the year 2010 in the county Gorj**

<table>
<thead>
<tr>
<th>Issuing activities greenhouse gas</th>
<th>SO2(t)</th>
<th>NOx(t)</th>
<th>NH3(t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustion in energy and transformation industries</td>
<td>214754.29</td>
<td>29278.66</td>
<td></td>
</tr>
<tr>
<td>In non-industrial combustion plants</td>
<td>922.71</td>
<td>401.48</td>
<td>29.51</td>
</tr>
<tr>
<td>Combustion in manufacturing industry</td>
<td>18.56</td>
<td>236.48</td>
<td>0.47</td>
</tr>
<tr>
<td>Production processes</td>
<td>27.31</td>
<td>19.96</td>
<td>-</td>
</tr>
<tr>
<td>Road</td>
<td>156.00</td>
<td>1483.65</td>
<td>-</td>
</tr>
<tr>
<td>Other mobile sources and machinery</td>
<td>118.71</td>
<td>1056.68</td>
<td>0.15</td>
</tr>
<tr>
<td>Treatment and waste disposal</td>
<td>0.24</td>
<td>3.99</td>
<td>368.61</td>
</tr>
<tr>
<td>Agriculture</td>
<td>-</td>
<td>-</td>
<td>4196.98</td>
</tr>
<tr>
<td>Total</td>
<td>215997.82</td>
<td>32480.90</td>
<td>4605.73</td>
</tr>
</tbody>
</table>

Emissions of gases with acid forming greenhouse effect (SO2, NOx, NH3), for the period 2005-2010 in graphically represented in figure 3.
The acidity of the atmosphere is mainly provoked by compounds containing sulphur and azoth. These are formed as a result of emitting, in the atmosphere, of sulphur dioxide (SO2), azoth oxides (NOx) and ammonia (NH3).

APM Gorj realised the monitoring of the polluters SO2, NOx and NH3 in the areas: Târgu-Jiu-3 sample taking points (average tests 24h), Rovinari-1 sample taking point (average test 24h), Turceni-1 sample taking point (tests 30’) and Motru-1 sample taking point (tests 30’). The concentrations of SO2, NOx and NH3 resulted from the process of monitoring exceeded the critical thresholds.

In figure 4 is presented the monthly average concentration for pollutant NO2, 24h.

**Fig. 4. The monthly average concentration for pollutant NO2, 24h**

The middle annual concentrations of the sulphur dioxide have been smaller than annual CMA (0,06mg/m3), namely APM Târgu-Jiu-0,0021mg/m3, Meteo Târgu-Jiu-0,0021mg/m3, CNLO Targu-Jiu-0,0027mg/m3, Rovinari-0,0020mg/m3 and are presented in figure 5.

**Fig. 5 The middle annual concentrations of the sulphur dioxide**

For sulphur dioxide, the average annual concentrations exceeded the annual CMA (0,040mg/m3), values being situated between 0.0044mg/m3 (Meteo Targu-Jiu) and 0,0102 mg/m3 (CNLO Targu-Jiu). Regarding the samples taking points from Turceni and Motru (short period average tests, 30min), the registered values are positioned under the correspondent CMA. The annual average concentrations for ammonia (fig.6) is positioned between mg/m3 (Meteo Targu-Jiu) and 0,0356mg/m3 (CNLO Targu-Jiu).
2.3. Pollution of the environmental air with dusts in suspension and depositing dusts
Dusts in suspension and depositing dusts are the main pollutants from Gorj county, for which CMS exceeding are significant. In Gorj county, the most important dust pollution sources are: for Rovinari area: Energetic Complex Rovinari, quarry mining exploitations, road traffic; for Turceni area: Energetic Complex Turceni, road traffic; for areas Motru, Mătasări, Seciuri, Jilt-quarry mining exploitation, road traffic; for area Meri- Meri Quarry- figure 7.

The indicator of depositing dusts was determined in 52 sample taking points in the area of Gorj county, positioned in the areas: Târgu Jiu, Rovinari, Turceni, Barsesti, Motru, Matasari, Meri, Tg Cârbunesti, Pleșa, Timișeni, Telești, Jilt and are presented in figure 8 [3].
Fig. 8. Graphical representation of dust depositing in the county Gorj in 2010

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STUDY UPON THE CAVITATION PHENOMENON OF THE ROTORS

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Abstract: The main problem of the hydrodynamics of cavitation implosion of a single bubble, consists in pressure and velocity fields determination, including the collapse velocity of the bubble wall. By analysis the theoretic and experimental phenomenon it establish the implicit function which describes this phenomenon. By application the Π theorem for this implicit function it finds the criterion equation of phenomenon.

Depending on operating condition various cavitation patterns can be observed on a body surface as travelling bubbles, attached sheet cavitation, shear cavitation or vortex cavitation. Leading edge attached partial cavitation is commonly encountered on rotor blades or on hydrofoil. It corresponds to the case for which a vapor cavity is attached in the vicinity of the leading edge and extends over a fraction of the foil surface. It generally takes places at incidence angles for which a leading edge pressure peak occurs and reduced below the liquid vapor pressure. At the early phases of development, leading edge partial cavitation is steady.

Keywords: The bubble’s implosion, incompressible liquid, the bubble surface, the Π theorem.

1. Using the similitude theory on two scales in the experimental study of the cavitation phenomenon

There are situations when the possibilities of accomplishment of the pattern impose exceptions from the complete geometrical similitude, obtaining this way the distorted patterns which have horizontal lengths and vertical lengths reduced to different scales.

Generally, the distorted patterns are imposed when the possibilities of practical accomplishment make impossible the exact conformation of the geometrical similitude between the pattern and the prototype, or when evolution of the phenomenon on the pattern made at a single scale would lead to a laminar movement instead of turbulent one which would make all the experiments difficult.

A random physical phenomenon can be expressed in the most general way through a function of several physical proportions and the establishment of the connection between them is made (when the number of the physical proportions $n \geq 5$) through theorem $Π$.

Any homogeneous function of several physical proportions which determine a physical phenomenon can always be reduced to a relation between dimensionless complex proportions of the following formula:

$$\Phi(\Pi_1, \Pi_2, \ldots, \Pi_{n-k}) = 0$$  \hspace{1cm} (1)

In the theory of similitude this function is called criteria equation and its establishment represents the first phase of the pattern study of a phenomenon.

As it is known the cavitation problems have not yet been solved, theoretically or practically, worldwide, although researches are made to this respect.

If we want to study this phenomenon through the similitude theory, we should previously set the physical proportions that intervene within the evolution of the cavitation phenomenon on the rotor of the axial pumps.

The criteria equation for the cavitation phenomenon produced at the wheels of the axial pumps

After theoretical and experimental researches made until now, it has been established that the cavitation phenomenon at the rotor of the axial pumps has the following implicit function:
\[
f(\rho, n, D, T, \Delta p, h, d_{\text{max}}, g, \eta, v, m, z) = 0
\]

where:
- \(\rho\) - water density
- \(n\) - wheel speed
- \(D\) - wheel diameter
- \(T\) - wheel pusher
- \(\Delta p = p - p_v\) - pressure distribution on the blade
- \(p_v\) - water vaporization pressure at certain temperature;
- \(h\) - immersion of the wheel axis on the water surface
- \(d_{\text{max}}\) - maximum thickness of the wheel blade;
- \(g\) - gravitational velocity \(g = 9.81 \text{ m/s}^2\);
- \(\eta\) - water kinetic viscosity;
- \(v\) - current velocity through the rotor disk;
- \(m\) - air volume dissolved in water;
- \(z\) - number of the wheel blades.

The physical proportions of this implicit function actually represent the physical proportions which this phenomenon depends on.

In order to apply theorem \(\Pi\) to the implicit function, we first write the dimensional matrix of the variables (number of rotor blades \(z\) is the same both as pattern and prototype).

\[
\begin{bmatrix}
\rho & n & D & T & \Delta p & h & d_{\text{max}} & g & \eta & v & m \\
-3 & 0 & 1 & 1 & -1 & 1 & 1 & -1 & 1 & 0 \\
Kg & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 1 \\
s & 0 & -1 & 0 & -2 & -2 & 0 & 0 & -2 & -1 & -1 & 0 \\
\end{bmatrix}
\]

out of which we obtain the equations system:

\[
\begin{align*}
-3x_1 + x_3 + x_4 - x_5 + x_6 + x_7 + x_8 - x_9 + x_{10} &= 0 \\
x_1 + x_4 + x_5 + x_9 + x_{11} &= 0 \\
-x_2 - 2x_4 - 2x_5 - 2x_8 - x_9 - x_{10} &= 0
\end{align*}
\]

We sort out the main variables of the system:

\[
\begin{align*}
x_1 &= -x_4 - x_5 - x_9 - x_{11} \\
x_2 &= -2x_4 - 2x_5 - 2x_8 - x_9 - x_{10} \\
x_3 &= -4x_4 - 2x_5 - x_9 - x_8 - 2x_9 - x_{10} - 3x_{11}
\end{align*}
\]

System (4) is undetermined for solving, so we apply the Cramer rule and we obtain the solution matrix as it follows:
Out of the solution matrix we obtain the following similitude criteria:

\[
\begin{align*}
\Pi_1 &= \frac{T}{\rho n^2 D^4}; \\
\Pi_2 &= \frac{p - p_v}{\rho n^2 D^2}; \\
\Pi_3 &= \frac{h}{D}; \\
\Pi_4 &= \frac{d_{\text{max}}}{D}; \\
\Pi_5 &= \frac{g}{n^2 D^2}; \\
\Pi_6 &= \frac{\eta}{\rho n D^2}; \\
\Pi_7 &= \frac{v}{n D}; \\
\Pi_8 &= \frac{m}{\rho D^3}
\end{align*}
\]  

(6)

The criteria equation in which we shall include the number of blades \( z \), shall be as it follows:

\[
\phi\left(\frac{T}{\rho n^2 D^4}, \frac{p - p_v}{\rho n^2 D^2}, \frac{h}{D}, \frac{d_{\text{max}}}{D}, \frac{g}{n^2 D^2}, \frac{\eta}{\rho n D^2}, \frac{v}{n D}, \frac{m}{\rho D^3}, z \right) = 0
\]  

(7)

If we respect the geometrical similitude after a single scale, it is possible that the thickness of the wheel blade and the immersion of its axis to reduce a lot, therefore it is possible that the pattern not to be able to be used for determinations, the results including too many errors.

Because of this, it is more advantageous and safe to create the distorted blade pattern (at two scales), which allows more accurate results.

It can be determined the pattern law in the case of similitude at two scales, by randomly choosing the scale of the parallel lengths with the blade diameter and the scale of the parallel lengths with the thickness of the blade.

2. Experimental results and discussions

An investigation of leading edge partial cavitation was performed in Romania (ICEPRONAV – Galati) including the conditions of cavitation inception, the cavitation patterns together with cavity length measurements. The investigation was enhanced by instantaneous wall-pressure measurements using an instrumented blade of rotor equipped with seventeen wall-pressure transducers mounted into small cavities, (fig 1). All the experiments fitted with a 1m long and 0.192 m wide square cross test section. In this device, velocities of up to 15 m/s and pressures between 30 mbar and 3 bar can achieved.
The designed blade for this project is a 0.191 mm span two-dimensional cambered foil of the NACA 66. Several experimental results have been obtained. Figure 2 shows the inception conditions and the various patterns detected on the suction side of the foil versus the cavitation number and the angle of incidence. The inception conditions are also compared to the theoretical values of the opposite of the minimum pressure coefficient on the suction side. Partial cavities of intermediate length (l* lower than about 0.5) have a relatively stable behavior with weak variation of the cavity closure while shedding U-shaped vapor structures in the wake. In that situation the cavity length was measurable (see fig. 3). As shown on fig. 4, the liquid-vapor interface has a glossy aspect over a short distance from the leading edge indicative of a laminar boundary layer developing on the interface. The extent of the laminar flow was found to be dependent on the velocity (Figures 4.b and 4.c for the same cavitation number but two velocities). Further away the interface becomes wavy and unstable over a large fraction of the cavity length. When the cavity becomes large, typically l/c larger than about 0.5, it exhibits a pulsating behavior while shedding larger vapor-filled structures. The transition is relatively well represented by the straight line shown on fig 1.
3. Conclusions

Used in distributions, the equations form in the fluid mechanics and the filtration property of the Dirac distribution, several integral formulas regarding the cavitational implosion are obtained.

The mathematic pattern, which only describes the fluid movement, can only indicate something about the hydrodynamic effects of the cavitational implosion, the thermal and electrochemical effects, experimentally presented, can be analogously analyzed.

After knowing the non dimensional complex numbers which form the criteria equation, before making the pattern of the studied phenomenon we shall establish the connections between the scales of the physical proportions which determine these complex numbers, that is we shall establish the pattern law.

Being familiar to the distorted pattern law, we can transfer the proportions results obtained on the pattern, on the prototype.

We notice that not all the similitude criteria have the same importance in the evolution of the cavitation process of the axial pumps blades. The most important criterion, decisive in the cavitation process, is the one in which the vaporization pressure intervenes $p_v$.

The cavity length does not change significantly, the liquid – vapor interface is smooth and has a glossy aspect along a short distance from the leading edge. At the end of the cavity it breaks partially into small bubbles. As the cavity expands, the liquid – vapor interface become distorted, wavy and unstable yielding to breakup and unsteadiness.
At this stage significant variations of the location of the cavity closure point are observed while shedding vapor structures called „cloud” cavitation. This process induces high-level pressure pulses and is known to be one of the most destructive forms of cavitation.

4. References
GROUPOIDS AND UNIFORMITIES ASSOCIATED TO IRREVERSIBLE DYNAMICAL SYSTEMS

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Abstract. The purpose of this paper is to introduce a groupoid associated to a dynamical system. We find this groupoid to be adequate for study of the dynamical system via computer visualization. The principal innovation in our approach to classical ([4] and [7]) is the use of a uniform structure on phase space which induce a non-Hausdorff topology.

Keywords: dynamical system; groupoid; uniform structure; visualization;

1. Introduction

This paper is motivated by a problem arising in the study of a dynamical system via computer visualization. In [1-2] we presented some possible visualizations of the properties of the orbit spaces associated to particular discrete dynamical systems. However because of the floating point arithmetic and continuous-discrete conversion, the interpretation of the visualized properties could be erroneous. Moreover in order to visualize n – dimensional (n≥3) data various projections are needed, and in addition the way to recover the high-dimensional structure from low-dimensional representations are required ([3], [5]). In this short paper we shall introduce a new groupoid reflecting the limitations of the visual images associated to the dynamical system. Furthermore we expect that comparative study of this groupoid and of the original groupoid associated to the dynamical system as in [4] and [7] to facilitate a correct interpretation of the visualized property of the dynamical system.

2. Space, time and time evolution

The dynamics of the system will be study in the framework of groupoids similar as in [4] or [7]. More precisely, we start with an abstract dynamical system given by a space, time, and a time evolution. As in [6] the phase space is a set with some additional structure, whose elements or points represent possible states of the system. Time may be discrete or continuous and may be reversible or irreversible (i.e. parametrized by a group or a semigroup). The time-evolution law is represented by the action of time, given by the (semi-) group, on the phase space X. Classically the group real numbers parametrizes a reversible continuous-time process, and nonnegative real numbers an irreversible one, the group integer numbers parametrizes a reversible discrete-time process, and the natural numbers an irreversible one. Also classically, the continuous-time evolution is given by an ordinary differential equation of the form \( \frac{dx}{dt} = F(x) \) (satisfying the Lipschitz existence condition), where x is state-valued function.

However as is [4] or [7] we shall work in a more abstract setting. We shall consider a group H and a subsemigroup P of H such that the identity e\(\in\)P. A right action of P on a space X is a map \( \theta: X \times P \rightarrow X \), \( \theta(x,n) = x \cdot n \) such that

1. \( x \cdot e = x \) for all \( x \in X \)
2. \( x \cdot mn = (x \cdot m) \cdot n \) for all \( x \in X \) and \( m, n \in P \).
We shall consider that the phase space is endowed with a uniform structure. Let us recall few aspects concerning the uniform structure. A uniform space is a set $X$ equipped with a nonempty family $US$ of subsets of $X \times X$ satisfying the following conditions:

1. if $U \in US$, then $\Delta \subseteq U$, where $\Delta = \{(x, x) : x \in X\}$.
2. if $U \in US$ and $V$ is subset of $X \times X$ which contains $U$, then $V \in US$
3. if $U \in US$ and $V \in US$, then $U \cap V \in US$
4. if $U \in US$, then there exists $V \in US$ such that $VV \subseteq U$, where $VV = \{(x, z) : \text{there is } y \text{ such that } (x, y) \in V \text{ and } (y, z) \in V\}$
5. if $U \in US$, then $U^{-1} = \{(y, x) : (x, y) \in U\}$ is also in $US$.

The family of sets $US$ is called uniform structure or uniformity of $X$ and its elements entourages or surroundings. A fundamental system of entourages of a uniform structure $US$ is any set $B$ of entourages of $US$ such that every entourage of $US$ contains a set belonging to $B$. If $B$ is a fundamental system of entourages, then the uniform structure $US$ is the set of subsets of $X \times X$ that contain a set in $B$.

A particular case of uniform space is a metric space $(X, d)$. The sets $U_\varepsilon = \{(x, y) \in X \times X : d(x, y) \leq \varepsilon\}, \varepsilon > 0$ form a fundamental system of entourages for the standard uniform structure of $X$.

If $f : X \to Y$ is a function and $SU$ is a uniform structure on $Y$, then set of subsets of $X \times X$ that contain a set of the form $(f, f)^{-1}(U)$ with $U \in US$ is a fundamental system of entourages of a uniform structure on $X$. More generally, if $\{f : X \to Y, f \in F\}$ is a family of functions and $SU$ is a uniform structure on $Y$, then set of subsets of $X \times X$ that contain a finite intersections of set of the form $(f, f)^{-1}(U)$ with $U \in US$ is a fundamental system of entourages of a uniform structure on $X$.

3. Groupoids associated to the dynamical systems

A groupoid is like a group with multiplication only partially defined. More precisely, a groupoid is a set $G$, together with a distinguished subset $G(2) \subseteq G \times G$, and two maps: a product map $\gamma_1, \gamma_2 \to \gamma_1 \gamma_2 : [G(2) \to G]$, and an inverse map $\gamma \to \gamma^{-1} : [G \to G]$, such that the following relations are satisfied:

1. $(\gamma^{-1})^{-1} = \gamma$
2. If $(\gamma_1, \gamma_2) \in G(2)$ and $(\gamma_2, \gamma_3) \in G(2)$, then $(\gamma_1 \gamma_2, \gamma_3) \in G(2)$ and $(\gamma_1 \gamma_2) \gamma_3 = \gamma_1 (\gamma_2, \gamma_3)$.
3. $(\gamma, \gamma^{-1}) \in G(2)$, and if $(\gamma_1, \gamma) \in G(2)$, then $(\gamma_1 \gamma) \gamma^{-1} = \gamma_1$.
4. $(\gamma^{-1}, \gamma) \in G(2)$, and if $(\gamma, \gamma_1) \in G(2)$, then $\gamma^{-1}(\gamma \gamma_1) = \gamma_1$.

The maps $r$ and $d$ on $G$, defined by the formulae $r(\gamma) = \gamma^{-1}$ and $d(\gamma) = \gamma^{-1} \gamma$, are called the range and the source (domain) maps. It follows easily from the definition that they have a common image called the unit space of $G$, which is denoted $G^0$. The relation $x \sim y$ if and only if there is $\gamma \in G$ such that $r(\gamma) = x$ and $d(\gamma)$ is an equivalence relation on $G^0$. Its equivalence classes are called orbits.

Notation 3.1. Let $H$ be a group and $P$ be a subsemigroup of $H$ such that the identity $e \in P$. Let us assume the $P$ acts on right on a uniform space $X$ and that that $P^1 P \subseteq PP^1$. Let $\emptyset$ denotes the right action. Let US be a uniform structure on $X$.

Remark 3.2. We are interesting in the following uniform structures on $X$. Let us assume that $X \subseteq \mathbb{R}^3$ (more generally suppose that there is an injective function $i : X \to \mathbb{R}^3$ and
\[ A: \mathbb{R}^n \rightarrow \mathbb{Z}^2 \subset \mathbb{R}^2 \] be the composition of a projection transform (camera space --> screen space) with a viewing transform (world space --> camera space) and a modeling transform (model space --> world space). Let us consider \( \mathbb{R}^2 \) endowed with one of the following uniform structures given by the fundamental systems of entourages:

\[
U_\varepsilon = \{(x_1, x_2, y_1, y_2) \in \mathbb{R}^2 \times \mathbb{R}^2 : |y_1-x_1| \leq \varepsilon \text{ and } |y_2-x_2| \leq \varepsilon \}, \varepsilon > 0
\]

\[
V_\varepsilon = \{(x_1, x_2, y_1, y_2) \in \mathbb{R}^2 \times \mathbb{R}^2 : |y_1-x_1| + |y_2-x_2| \leq \varepsilon \}, \varepsilon > 0
\]

Then \( \{(A,A)^{-1}(U_\varepsilon), \varepsilon > 0\} \cap (X \times X) \) (respectively, \( \{(A,A)^{-1}(V_\varepsilon), \varepsilon > 0\} \cap (X \times X) \)) is a fundamental system of entourages of a uniform structure US on X.

**Definition 3.3.** Let us define the following preorder relation (reflexive and transitive) on the group H:

\[ n \leq m \iff n^{-1}m \in P, \text{ or equivalently there is } i \in P \text{ such that } m = ni \]

If we consider the restriction of this relation on P, then (P, \( \leq \)) is directed set. Indeed, let \( n_1, n_2 \in P \) (respectively, \( n_1, n_2 \in H \)). Since \( P^{-1}P \subset PP^{-1} \), it follows that there are \( m_1, m_2 \in P \) such that \( n_1^{-1}n_2 = m_1^{-1}m_2^{-1} \), or equivalently, \( n_1m_2 = n_1m_1 \). Thus \( n_1 \leq n_1m_1 \) and \( n_2 \leq n_2m_2 \). We shall also use the following relation \( m \geq n \iff n \leq m \).

**Definition 3.4.** For \( x, y \in X \) and \( k \in H \), let us define the following relation:

\[ x \sim_k y \iff \text{there is } n \in P \text{ such that } kn \in P \text{ and for all } U \in US \text{ and all } i \in P, i \geq n \text{ we have } (x \cdot k^{-1}i, y \cdot i) \in U \]

Let us notice that if \( kn \in P \) and \( i \geq n \), then \( kn^{-1}i \in PP^{-1} \), it follows that there are \( m_1, m_2 \in P \) such that \( m_1 = n_1^{-1}m_2 \), or equivalently, \( m_2 = n_1 \). Thus \( n_1 \leq m_1 \) and \( n_2 \leq m_2 \). We shall also use the following relation \( m \leq n \iff n \geq m \).

**Lemma 3.5.** 1) If \( x, y \in X \) and \( k \in H \), then \( x \sim_k y \iff y \sim_{k^{-1}} x \).

2) For every \( U \in US \) there is \( V \in US \) such that \( VV \subset U \).

Proof. 1) Let \( n \in P \) such that \( kn \in P \). For every \( j \geq m \), there is \( i \in P \) such that \( j = ki \). Indeed since \( j \geq m \), there is \( q \in P \) such that \( j = m = qnq \). If we take \( i = nq \), then \( i \geq n \) and \( j = ki \). Moreover

\[ (y \cdot k^{-1}(ki), x \cdot i) \in U \iff (y \cdot i, x \cdot ki) \in U \iff (x \cdot ki, y \cdot i) \in U^{-1} \]

Hence taking into account that \( U \in US \iff U^{-1} \in US \), it is easy to see that

\[ x \sim_k y \iff y \sim_{k^{-1}} x \]

2) For every \( U \in US \) there is \( V \in US \) such that \( VV \subset U \). Since \( x \sqsupset_k y \) (respectively, \( y \sqsupset_{k^{-1}} x \)), there is \( n_1 \in P \) (respectively, \( n_2 \in P \)) such that \( k1n1 \in P \), (respectively, \( k2n2 \in P \)) and all \( i \in P, i \geq n_1 \) (respectively, \( i \geq n_2 \)) \( (x \cdot ki, y \cdot i) \in V \) (respectively, \( (y \cdot k^{-2}, z \cdot i) \in V \). Let \( m_1, m_2 \in P \) be such that \( k1 = m_1n_1^{-1} \), \( k2 = m_2n_2^{-1} \). Since \( P^{-1}P \subset PP^{-1} \), it follows that there are \( i_1, i_2 \in P \) such that \( n_1^{-1}m_2 = i_1i_2^{-1} \), or equivalently, \( m_2i_2 = n_1i_1 \). If we take \( n_3 = n_3i_2 \in P \), then \( n_2 \geq n_2 \) and \( k2n3 = m_2n_2^{-1}n_3i_2 = m_2i_2 = n_1i_1 \). Consequently, for all \( j \geq n_3 \), we have \( (x \cdot k1k2j, y \cdot k2j) \in V \) and \( (y \cdot k2j, z \cdot j) \in V \). Therefore \( (x \cdot k1k2j, z \cdot j) \in VV \subset U \).
**Proposition 3.6.** Let us consider the set
\[ G(X, P, H, θ, SU) = \{(x, k, y) \in X \times H \times X : x \sim_k y \} \]
This is a groupoid with the set of composable pairs being
\[ G(X, P, H, θ, SU)^{(2)} = \{((x_1, k_1, y_1), (y_2, k_2, z_2)) \in G(X, P, H, θ, SU) \times G(X, P, H, θ, SU) : y_1 = y_2 \} \]
and the inversion and multiplication given by:
\[ (x, k, y)^{-1} = (y, k^{-1}, x), (x, k_1, y)(y, k_2, z) = (x, k_1 k_2, z). \]

**Remark 3.7.** Let us consider
\[ G(X, P, H, θ) = \{(x, k, y) \in X \times H \times X : \text{there is } n \in P \text{ such that } kn \in P \text{ and } x \cdot kn = y \cdot n \} \].
Then \( G(X, P, H, θ) \) is a subgroupoid of \( G(X, P, H, θ, SU) \). \( G(X, P, H, θ) \) is the groupoid studied in [4] and [7] in the discrete case.
If the uniform structure induced a Hausdorff topology on \( X \), then \( G(X, P, H, θ, SU) = G(X, P, H, θ) \).

**References**


CONSIDERATIONS ON THE SELECTIVE MAINTENANCE MODEL FOR THE COMPLEX SYSTEMS

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Abstract: The paper presents the mathematical model of the selective maintenance as well as a numerical application of the method in the case of the remote control systems.

Keyword: Selective maintenance, reliability, remote control system

1. Introduction

The specialists within logistics and resources management are faced with the task of solving the equation “achieving an increased number of requirements with less resource” as budgets allocated to the companies decline, and operational requirements increase. In order to fulfill the missions it is necessary to achieve the full readiness status of the complex systems from the inventory. The changes of the operational scenario generated the changes of the maintenance concept from a repair function to one focuses on the mission. Due to the fact that many of the remote control systems are needed to perform several missions per day the maintenance structures must decide which systems to repair in the time allotted between missions. As well as the problem of solving of an increased number of requirements with reduced resources is applied to the industrial environment in order to ensure the operational efficiency of the technical systems [1], [2]. In this context the present paper proposes a selective maintenance model which can be used to identify the necessary maintenance activities in order to optimize the mission’s requirements. However the model can be also applied to the industrial systems which use equipments involved in serial technological operations.

Consider a system composed of \( m \) independent subsystems (subsystem 1, subsystem 2, and subsystem \( m \)) connected in series. Let each subsystem \( i \) contain a set of \( z_i \) independent components connected in different ways. Each component in the system is defined by \( (i,j) \) where \( i \) define the subsystem number and \( j \) define the component number. Each component, subsystem, and the system can be in only one of two states: functioning properly or failed. This type of complex system configuration represents a wide variety of equipment utilized in industrial environments [3].

Assume the system is required to perform a sequence of identical missions with breaks of known length between missions. At the beginning of a mission, say mission \( k \), the status of a component is defined according to those presented in Table no.1.

**Table no.1**

<table>
<thead>
<tr>
<th>Component status ( X_{ij}(k) )</th>
<th>Status value</th>
<th>Status significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>( X_{ij}(k) = 1 )</td>
<td>Component ( i ) of the subsystem ( j ) is working at the beginning of the mission ( k )</td>
<td></td>
</tr>
<tr>
<td>( X_{ij}(k) = 0 )</td>
<td>Other status</td>
<td></td>
</tr>
</tbody>
</table>

The status of a subsystem at the beginning of the mission is defined according to those presented in Table no.2.
The status of the system at the beginning of the mission is defined according to those presented in Table no. 3.

**Table no.3**

<table>
<thead>
<tr>
<th>System status</th>
<th>Status value</th>
<th>Status significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>( X(k) )</td>
<td>1</td>
<td>System is working at the beginning of the mission ( k )</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>Other status</td>
</tr>
</tbody>
</table>

The status of the system at the beginning of the mission is a resultant of the status of its component subsystems being defined by

\[
X(k) = \prod_{i} X_i(k)
\]  

(1)

Similar can be defined the functioning status at the end of the mission. The status of the component is defined according to those presented in Table no. 4.

**Table no.4**

<table>
<thead>
<tr>
<th>Component status</th>
<th>Status value</th>
<th>Status significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Y_{ij}(k) )</td>
<td>1</td>
<td>Component ( i ) of the subsystem ( j ) is functioning at the end of the mission ( k )</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>Other status</td>
</tr>
</tbody>
</table>

The status of a subsystem at the end of the mission is defined according to those presented in Table no. 5.

**Table no.5**

<table>
<thead>
<tr>
<th>Subsystem status</th>
<th>Status value</th>
<th>Status significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Y_i(k) )</td>
<td>1</td>
<td>Subsystem ( i ) is working at the end of the mission ( k )</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>Other status</td>
</tr>
</tbody>
</table>

The system status at the end of the mission is defined according to those presented in Table no. 6.

**Table no.6**

<table>
<thead>
<tr>
<th>System status</th>
<th>Status value</th>
<th>Status significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Y(k) )</td>
<td>1</td>
<td>System is working at the end of the mission ( k )</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>Other status</td>
</tr>
</tbody>
</table>

The status of the system at the end of the mission is a resultant of the status of its components subsystems being defined by

\[
Y(k) = \prod_{i} Y_i(k)
\]  

(1)
The performance of a component, subsystem or system can be measured in many ways. For the purposes of maintenance planning, performance is typically measured by reliability. Let $f_{ij}$ define the probability that component $j$ of subsystem $i$ does not failed during a particular mission, say mission $k$. Thus,

$$f_{ij} = P(Y_{ij}(k) = 1 | X_{ij}(k) = 1)$$

(3)

We emphasize that $f_{ij}$ is the same for any given mission. This is based on the followings assumptions:
- missions are identical;
- all components have a constant failure rate.

The reliability of the component $j$ of the subsystem $i$ during the mission $k$ is given by

$$P(Y_{ij}(k) = 1) = f_{ij}X_{ij}(k)$$

(4)

For a subsystem $i$ the reliability during the mission $k$ is defined based on the its components reliabilities

$$F_i(k) = P(Y_i(k) = 1)$$

(5)

The reliability of the system for the mission $k$ is defined by [4], [5]

$$F(k) = P(Y(k) = 1) = \prod_{i=1}^{m} F_i(k)$$

(6)

At the completion of a particular mission, say mission $k$, each component in the system is either functioning or failed. In the best situation, all failed components (those components having $Y_{ij}(k) = 0$) would be repaired prior to the beginning of the next mission. However, it may not be possible to repair all the failed components. Let $t_{ij}$ define the amount of time required to repair component $j$ of subsystem $i$. The total time required to repair all failed components in the system prior to the next mission, mission $k + 1$, is given by

$$T(k) = \sum_{i=1}^{m} \sum_{j=1}^{n} t_{ij}(X_{ij}(k+1) - Y_{ij}(k))$$

(7)

where $X_{ij}(k+1)$ represent the status of the components at the beginning of the next mission.

Suppose the total amount of time allotted to perform maintenance upon failed components between missions is $T_0$ time units. If

$$\sum_{i=1}^{m} \sum_{j=1}^{n} t_{ij}(X_{ij}(k+1) - Y_{ij}(k))T_0$$

(8)

then all failed components cannot be repaired prior to beginning the next mission.

In this situation a method is needed to decide which failed components should be repaired prior to the next mission.

2. Mathematical Programming Model

For the case in which the time allotted for maintenance is insufficient to repair all failed components in the system, a mathematical programming model is defined for assisting in the selective maintenance decision. The first step in the formulation of this model is the identification of the decision variables for the model. Given the status of each component at the end of a certain mission (the $Y_{ij}(k)$ values), the selective maintenance decision consists of identifying the failed components (those components having $Y_{ij}(k) = 0$) to be repaired prior to the next mission. This decision can be represented mathematically by specifying the $X_{ij}$
values for the next mission. Thus, the $X_{ij}(k + 1)$ values serve as the decision variables for the mathematical programming model.

The next step in formulating the mathematical programming model for this selective maintenance problem is the construction of the objective function. Initially, assume that the objective in performing selective maintenance is to maximize the system reliability for the next mission. Therefore, the objective function is given by

$$F(k+1) = \prod_{i=1}^{n} F_i(k + 1)$$

where $F(k+1)$ represents the system reliability for the next mission and $F_i(k + 1)$ define the reliability function of subsystem $i$ for the next mission.

The final step in formulating this selective maintenance mathematical programming model is the construction of the constraints on the decision variables. Thus we have the followings:

- all maintenance activities be completed within the allotted time.

$$\sum_{i=1}^{n} \sum_{j=1}^{m} t_i (X_{ij}(k + 1) - Y_{ij}(k)) T_o$$

- the decision variables are restricted to binary values

$$X_{ij}(k + 1) \text{ binary for } \forall i, j$$

- a component's status at the beginning of the next mission must be at least as good as its status at the end of the previous mission.

$$X_{ij}(k + 1) \geq Y_{ij}(k) \text{ for } \forall i, j$$

Based on those above presented we can define the selective maintenance problem as follows [6]:

$$\text{Maximize } F(k+1) = \prod_{i=1}^{n} F_i(k + 1)$$

in the followings conditions

$$\sum_{i=1}^{n} \sum_{j=1}^{m} t_i (X_{ij}(k + 1) - Y_{ij}(k)) T_o$$

$$X_{ij}(k + 1) \geq Y_{ij}(k) \text{ for } \forall i, j$$

$$X_{ij}(k + 1) \text{ binary for } \forall i, j$$

This model is deterministic in that all the model parameters (end-of-mission status values, component reliabilities, component maintenance times, total allotted time for maintenance) are assumed to be known constants.

3. Selective maintenance for the remote control system

In order to present the application of the above mentioned model we consider the case of a remote control system which is designed to equipped the armored vehicles. The components of the remote control system are presented in Table no. 7.
The reliability diagram of the remote control system defined above is presented in Fig. no. 1

![Reliability diagram](image)

The formulae for the reliability calculus [3] of the component systems of the remote control system are presented in the followings

\[
F_1(k+1) = 1 - (1 - f_{11}X_{11}(k+1))(1 - f_{12}X_{12}(k+1))(1 - f_{13}X_{13}(k+1))
\]

(17)

\[
F_2(k+1) = 1 - (1 - f_{21}X_{21}(k+1))(1 - f_{22}X_{22}(k+1))
\]

(18)

\[
F_3(k+1) = 1 - (1 - f_{31}X_{31}(k+1))(1 - f_{32}X_{32}(k+1))(1 - f_{33}X_{33}(k+1))(1 - f_{34}X_{34}(k+1))
\]

(19)

The values of the specific parameters for the analyzed system are presented in the Table no. 8.

### Table no. 7

<table>
<thead>
<tr>
<th>No.</th>
<th>System</th>
<th>Subsystem</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fire control system (S1)</td>
<td>Target tracking system (S11)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Computing system (S12)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Main system driving gear system (S13)</td>
</tr>
<tr>
<td>2</td>
<td>Main system (S2)</td>
<td>Acting component (S21)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Feeder (S22)</td>
</tr>
<tr>
<td>3</td>
<td>Command and control system (S3)</td>
<td>Acquisition data module from fire control system (S31)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Acquisition data module from main system (S32)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Acquisition data module from electrono-optic system (S33)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Integration/processing/command module at system level (S34)</td>
</tr>
</tbody>
</table>

### Table no. 8

<table>
<thead>
<tr>
<th>Subsystem(i)</th>
<th>Component (j)</th>
<th>( f_{ij} )</th>
<th>( t_{ij} )</th>
<th>( Y_{ij}(k) )</th>
<th>( X_{ij}(k+1) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>1</td>
<td>0.8</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>S1</td>
<td>2</td>
<td>0.8</td>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>S1</td>
<td>3</td>
<td>0.8</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>S2</td>
<td>1</td>
<td>0.7</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>S2</td>
<td>2</td>
<td>0.7</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>S3</td>
<td>1</td>
<td>0.9</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>S3</td>
<td>2</td>
<td>0.9</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>S3</td>
<td>3</td>
<td>0.9</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>S3</td>
<td>4</td>
<td>0.9</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
We consider as given the allotted maintenance time $T_0=10$ time units. According to the above mentioned data the necessary maintenance time for all the failed components before the next mission is 15 time units. In order to solve the selective maintenance problem for the next mission must be repaired the component no. 2 belonging subsystem no. 1, component no. 1 belonging subsystem no. 2 and component no. 2 belonging subsystem no. 2. These repairs spend 7 time units (Table no. 9) and the result for reliability is the value 0.8936 (Table no. 10). The maximum reliability for the next mission is 0.9026 (Table no.11) which is obtained in the situation in which all the components are repaired.

### Table no.9

<table>
<thead>
<tr>
<th>Subsystem($i$)</th>
<th>Component ($j$)</th>
<th>$t_{ij}$</th>
<th>$Yij(k)$</th>
<th>$Xij(k+1)$</th>
<th>$t_{ij}[Xij(k+1)-Yij(k)]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>S1</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>S1</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>S2</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>S2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>S3</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>S3</td>
<td>2</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>S3</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>S3</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>T</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7</td>
</tr>
</tbody>
</table>

### Table no.10

<table>
<thead>
<tr>
<th>Subsystem($i$)</th>
<th>Component ($j$)</th>
<th>$f_{ij}$</th>
<th>$Xij(k+1)$</th>
<th>$1-f_{ij}*Xij(k+1)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>1</td>
<td>0.8</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td>S1</td>
<td>2</td>
<td>0.8</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td>S1</td>
<td>3</td>
<td>0.8</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>$R_1$</td>
<td></td>
<td></td>
<td>0.992</td>
</tr>
<tr>
<td>S2</td>
<td>1</td>
<td>0.7</td>
<td>1</td>
<td>0.3</td>
</tr>
<tr>
<td>S2</td>
<td>2</td>
<td>0.7</td>
<td>1</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>$R_2$</td>
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<td></td>
<td>0.91</td>
</tr>
<tr>
<td>S3</td>
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<td>0.9</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>S3</td>
<td>2</td>
<td>0.9</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>S3</td>
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<td>0.9</td>
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<td>1</td>
</tr>
<tr>
<td></td>
<td>$R_3$</td>
<td></td>
<td></td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>$R$</td>
<td></td>
<td></td>
<td>0.8936</td>
</tr>
</tbody>
</table>

### Table no.11
4. Generalization of the Selective Maintenance Model

According to those above, a finite amount of time, $T_o$, was allotted for making repairs to the failed components. However, in many cases, both time and cost constrain the maintenance activities performed between missions. Let $c_{ij}$ define the cost to repair component $j$ of subsystem $i$. Suppose the total cost of repairs between two missions may not exceed $C_o$. The total cost of repairing selected failed components in the system prior to the next mission, say mission $k + 1$, is given by

$$c(k) = \sum_{i=1}^{n} \sum_{j=1}^{m} c_{ij}(X_{ij}(k+1) - Y_{ij}(k))$$  \hspace{1cm} (20)

The cost constraints which can be added to the selective maintenance model suppose that all maintenance activities are required to be completed within the allotted cost. Thus

$$\sum_{i=1}^{n} \sum_{j=1}^{m} c_{ij}(X_{ij}(k+1) - Y_{ij}(k)) \leq C_o$$  \hspace{1cm} (21)

Adding this constraint to the model result a new selective maintenance optimization problem as follows [6]:

**Maximize** \hspace{1cm} $F(k+1) = \prod_{i=1}^{m} F_i(k+1)$  \hspace{1cm} (22)

in the following conditions

$\sum_{i=1}^{n} \sum_{j=1}^{m} f_i(X_{ij}(k+1) - Y_{ij}(k)) \leq T_o$  \hspace{1cm} (23)

$\sum_{i=1}^{n} \sum_{j=1}^{m} c_{ij}(X_{ij}(k+1) - Y_{ij}(k)) \leq C_o$  \hspace{1cm} (24)

$X_{ij}(k+1) \geq Y_{ij}(k)$ for all $i,j$ \hspace{1cm} (25)

$X_{ij}(k+1)$ binary for all $i,j$ \hspace{1cm} (26)

In the above presented problem the objective is to maximize the system reliability in terms of time and cost constraints.

A similar variant of this problem could be defined by minimizing total repair time subject to cost and reliability constraints. Thus the new problem for selective maintenance optimization will be [6]:

**Minimize** \hspace{1cm} $c(k) - \sum_{i=1}^{n} \sum_{j=1}^{m} f_i(X_{ij}(k+1) - Y_{ij}(k))$  \hspace{1cm} (27)

in the following conditions

$\sum_{i=1}^{n} \sum_{j=1}^{m} f_i(X_{ij}(k+1) - Y_{ij}(k)) \leq T_o$  \hspace{1cm} (28)

$\prod_{i=1}^{m} F_i(k+1) \geq F_o$  \hspace{1cm} (29)
Another variant of the selective maintenance will be obtained by minimizing the total repairing time in terms of time and cost constraints.

\[
X_i(k+1) \geq Y_i(k) \quad \text{for} \quad \forall i, j \tag{30}
\]

\[
X_i(k+1) \quad \text{binary} \quad \text{for} \quad \forall i, j \tag{31}
\]

5. Conclusions

The paper introduces and applies the selective maintenance concept for the complex systems and proposes a series of models in order to be used at the optimization of the decisions in that field. These can be applied to the remote control systems with fixed mission lengths and limited time between missions for maintenance. The calculus example emphasized the way by which the components could be selected in order to be repaired.

The selective maintenance concept could contribute to the enhancement of the remote control system performances as well as to the cost reducing during the life cycle system belonging to the current inventories. As well as the presented models underline the intricacy and validity of the selective maintenance problem.

References

KINEMATICS OF THE PLANAR QUADRILATERAL MECHANISM

Senior Lecturer Ph.D. Eng. Florian Ion PETRESCU, Senior Lecturer Ph.D. Eng. Victoria PETRESCU, Bucharest Polytechnic University

Abstract: This paper presents an original method to determine the kinematic parameters at the linked quadrilateral mechanism. It is starting with a trigonometric method, which has the advantage to determine very quickly the position angles. The velocities can be determined faster using a geometric method. This method is developed and for the accelerations determinations. The (proposed) geometric method, determines first the kinematic parameters of the internal couple (B) and then the rotation angles with their derivatives. Secondary, the paper presents the determination of the efficiency of this mechanism. Determines and dynamic coefficient, D. With this one proposes two yields; the mechanical efficiency and the dynamic efficiency.

Keywords: 3R dyad, cinematics, kinematic parameters, efficiency, dynamic coefficient

1. Introduction

The paper presents an original method to determine the kinematic parameters at the linked quadrilateral mechanism.

It is starting with a trigonometric method, which has the advantage to determine very quickly the position angles.

The velocities can be determined faster using a geometric method. This method is developed and for the accelerations determinations. The (proposed) geometric method, determines first the kinematic parameters of the internal couple (B) and then the rotation angles with their derivatives.

Secondary, the paper presents the determination of the efficiency of this mechanism. Determines and dynamic coefficient, D.

With this one proposes two yields; the mechanical efficiency and the dynamic efficiency.

Fig. 1. Kinematic schema of a planar quadrilateral mechanism
2. The kinematics of the planar quadrilateral mechanism

The kinematic schema of a planar quadrilateral mechanism can be seen in the Figure 1. The following kinematic parameters considered known:

\[ x_0; y_0; x_c; y_c; l_1; l_2; l_3; \phi; \omega \]

2.1. Determining the positions

It is starting with a trigonometric method, which has the advantage to determine very quickly the position angles (the system 1).

\[
\begin{align*}
\begin{cases}
  x_a = l_1 \cdot \cos \phi_1 & \dot{x}_a = -l_1 \cdot \sin \phi_1 \cdot \omega_1 \\
  y_a = l_1 \cdot \sin \phi_1 & \dot{y}_a = l_1 \cdot \cos \phi_1 \cdot \omega_1
\end{cases}
\end{align*}
\]

\[ l^2 = (x_a - x_c)^2 + (y_a - y_c)^2 \Rightarrow l = \sqrt{l^2} = \sqrt{(x_a - x_c)^2 + (y_a - y_c)^2} \]

\[ \cos A = \frac{l^2 + l_1^2 - l_3^2}{2 \cdot l \cdot l_2} \Rightarrow A = \arccos(\cos A); \quad \cos C = \frac{l^2 + l_3^2 - l_2^2}{2 \cdot l \cdot l_3} \Rightarrow C = \arccos(\cos C) \]

\[ \begin{align*}
  \cos \varphi &= \frac{x_a - x_c}{l} \\
  \sin \varphi &= \frac{y_a - y_c}{l}
\end{align*} \Rightarrow \varphi = \text{sign}(\sin \varphi) \cdot \arccos(\cos \varphi) \]

\[ \begin{align*}
  \varphi_2 &= \varphi - A \\
  \varphi_3 &= \varphi + C \\
  y_b &= y_c + l_3 \cdot \sin \varphi_3 \\
  x_b &= x_c + l_3 \cdot \cos \varphi_3
\end{align*} \]

(1)

2.2. Determining the velocities of the couple B

The velocities can be determined faster using a geometric method (the system 2).

\[
\begin{align*}
\begin{cases}
  (x_b - x_c)^2 + (y_b - y_c)^2 &= l_3^2 \\
  (x_b - x_a)^2 + (y_b - y_a)^2 &= l_2^2
\end{cases} \Rightarrow \begin{cases}
  (x_b - x_c) \cdot \dot{x}_b + (y_b - y_c) \cdot \dot{y}_b &= 0 \\
  (x_b - x_a) \cdot \dot{x}_b + (y_b - y_a) \cdot \dot{y}_b &= (x_b - x_a) \cdot \dot{x}_a + (y_b - y_a) \cdot \dot{y}_a
\end{cases}
\end{align*}
\]

\[ a_{11} = x_b - x_c; \quad a_{12} = y_b - y_c; \quad a_{21} = x_b - x_a; \quad a_{22} = y_b - y_a; \quad b_1 = 0; \quad b_2 = a_{21} \cdot \dot{x}_a + a_{22} \cdot \dot{y}_a \]

\[ \begin{align*}
  &a_{11} \cdot \ddot{x}_b + a_{12} \cdot \ddot{y}_b = b_1 \\
  &a_{21} \cdot \ddot{x}_b + a_{22} \cdot \ddot{y}_b = b_2
\end{align*} \Rightarrow \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \Delta = \begin{bmatrix} a_{11} \\ b_1 \\ a_{21} \\ b_2 \end{bmatrix}
\]

\[ \Delta x_b = \frac{a_{11} \cdot b_1}{a_{21} \cdot b_2} = a_{11} \cdot b_2 - a_{21} \cdot b_1; \quad \dot{x}_b = \frac{\Delta x_b}{\Delta}; \quad \dot{y}_b = \frac{\Delta y_b}{\Delta}
\]

(2)
2.3. Determining the accelerations of the couple B  The accelerations can be determined faster using a geometric method (the system 3).

\[
\begin{align*}
\left\{ \begin{array}{l}
(x_b - x_c) \cdot \ddot{x}_b + (y_b - y_c) \cdot \ddot{y}_b = -\dot{x}_b^2 - \dot{y}_b^2 \\
(x_b - x_d) \cdot \ddot{x}_b + (y_b - y_d) \cdot \ddot{y}_b = a_{21} \cdot \dddot{x}_b + a_{22} \cdot \dddot{y}_b - \dddot{a}_{21} - \dddot{a}_{22}
\end{array} \right.
\]

\[
c_1 = -\dot{x}_b^2 - \dot{y}_b^2, \quad c_2 = a_{21} \cdot \dddot{x}_b + a_{22} \cdot \dddot{y}_b - \dddot{a}_{21} - \dddot{a}_{22}
\]

\[
\begin{align*}
\{ a_{11} \cdot \dddot{x}_b + a_{12} \cdot \dddot{y}_b = c_1 \\
 a_{21} \cdot \dddot{x}_b + a_{22} \cdot \dddot{y}_b = c_2 \Rightarrow \Delta_{x_b} = \begin{bmatrix} c_1 \\ c_2 \end{bmatrix} = c_1 \cdot a_{22} - a_{12} \cdot c_2 \\
\Delta_{y_b} = \begin{bmatrix} a_{11} \\ a_{21} \end{bmatrix} = a_{11} \cdot c_2 - a_{21} \cdot c_1; \quad \ddot{x}_b = \frac{\Delta_{x_b}}{\Delta}; \quad \ddot{y}_b = \frac{\Delta_{y_b}}{\Delta}
\end{align*}
\]

(3)

2.4. Determining the angular velocities and accelerations  The angular velocities and accelerations can be determined now, faster, using the vectorial method (the system 4).

\[
\begin{align*}
\left\{ \begin{array}{l}
x_a - x_b = l_2 \cdot \cos \varphi_2 \\
y_a - y_b = l_2 \cdot \sin \varphi_2
\end{array} \right. \Rightarrow \omega_2 = \frac{(y_a - y_b) \cdot \cos \varphi_2 - (x_a - x_b) \cdot \sin \varphi_2}{l_2}
\]

\[
\begin{align*}
\ddot{x}_a - \ddot{x}_b = & \quad -l_2 \cdot \sin \varphi_2 \cdot \epsilon_2 - l_2 \cdot \cos \varphi_2 \cdot \omega_2^2 \cdot \left( -\sin \varphi_2 \right) \\
\ddot{y}_a - \ddot{y}_b = & \quad l_2 \cdot \cos \varphi_2 \cdot \epsilon_2 - l_2 \cdot \sin \varphi_2 \cdot \omega_2^2 \cdot \left( \cos \varphi_2 \right)
\end{align*}
\]

\[
\begin{align*}
\left\{ \begin{array}{l}
x_b - x_c = l_3 \cdot \cos \varphi_3 \\
y_b - y_c = l_3 \cdot \sin \varphi_3
\end{array} \right. \Rightarrow \omega_3 = \frac{(y_b - y_c) \cdot \cos \varphi_3 - (x_b - x_c) \cdot \sin \varphi_3}{l_3}
\]

\[
\begin{align*}
\ddot{x}_b - \ddot{x}_c = & \quad -l_3 \cdot \sin \varphi_3 \cdot \epsilon_3 - l_3 \cdot \cos \varphi_3 \cdot \omega_3^2 \cdot \left( -\sin \varphi_3 \right) \\
\ddot{y}_b - \ddot{y}_c = & \quad l_3 \cdot \cos \varphi_3 \cdot \epsilon_3 - l_3 \cdot \sin \varphi_3 \cdot \omega_3^2 \cdot \left( \cos \varphi_3 \right)
\end{align*}
\]

(4)
3. The efficiency of the planar quadrilateral mechanism

The efficiency of a planar quadrilateral mechanism can be determined starting from the forces and velocities repartition, (Figure 2).

![Diagram of forces and velocities repartition of a planar quadrilateral mechanism](image)

**Fig. 2.** Forces and velocities repartition of a planar quadrilateral mechanism

The system (5) presents the relationships which give the forces and the velocities on the planar quadrilateral mechanism. The driving force $F_m$ is perpendicular on the crank $1$ in $A$. Its component along the connecting rod (the bar 2) $F_n$ gives the normal component $F_{bn}$. $F_{bn}$ is perpendicular on the rocker $3$ in $B$.

These forces give the dynamic velocities which are similar with the forces.

The forces are always the same, but the velocities (the dynamic velocities) are different than the kinematics velocities.

For this reason the dynamic efficiency will be different than the mechanical yield.
\[
\begin{align*}
F_n &= F_m \cdot \sin(\phi_1 - \phi_2) \\
F_B &= F_m \cdot \sin(\pi - (\phi_3 - \phi_2)) = F_m \cdot \sin(\phi_1 - \phi_2) \cdot \sin(\phi_3 - \phi_2) \\
v_n &= v_m \cdot \sin(\phi_1 - \phi_2) \\
v_B &= v_m \cdot \sin(\pi - (\phi_3 - \phi_2)) = v_m \cdot \sin(\phi_1 - \phi_2) \cdot \sin(\phi_3 - \phi_2)
\end{align*}
\]

\[
\omega_3 = \frac{l_1 \cdot \sin(\phi_1 - \phi_2) \cdot \omega_1}{l_3 \cdot \sin(\phi_3 - \phi_2)} \Rightarrow v_B = l_3 \cdot \omega_3 = \frac{l_1 \cdot \omega_1 \cdot \sin(\phi_1 - \phi_2)}{\sin(\phi_3 - \phi_2)} = \frac{v_m \cdot \sin(\phi_1 - \phi_2)}{\sin(\phi_3 - \phi_2)}
\]

\[
v_B^D = D \cdot v_B \Leftrightarrow v_m \cdot \sin(\phi_1 - \phi_2) \cdot \sin(\phi_3 - \phi_2) = D \cdot \frac{v_m \cdot \sin(\phi_1 - \phi_2)}{\sin(\phi_3 - \phi_2)} \Rightarrow D = \sin^2(\phi_3 - \phi_2)
\]

\[
\eta_i = \frac{P_3}{P_1} = \frac{F_B \cdot v_B}{F_m \cdot v_m} = \frac{F_m \cdot \sin(\phi_1 - \phi_2) \cdot \sin(\phi_3 - \phi_2) \cdot \frac{v_m \cdot \sin(\phi_1 - \phi_2)}{\sin(\phi_3 - \phi_2)}}{F_m \cdot v_m} = \sin^2(\phi_1 - \phi_2)
\]

\[
\eta_i^D = \frac{P_3^D}{P_1} = \frac{F_B \cdot v_B^D}{F_m \cdot v_m} = \frac{F_m \cdot \sin(\phi_1 - \phi_2) \cdot \sin(\phi_3 - \phi_2) \cdot \frac{v_m \cdot \sin(\phi_1 - \phi_2) \cdot \sin(\phi_3 - \phi_2)}}{F_m \cdot v_m} = \sin^2(\phi_3 - \phi_2) \cdot \sin^2(\phi_1 - \phi_2) = D \cdot \eta_i
\]

(5)

Conclusions
The presented method is the most elegant and direct method to determine the kinematics planar quadrilateral mechanism.

Relationships used by this method allow and the determination of the dynamic system vibration. In the dynamic kinematics the constant rotation speed \(\omega_1 = ct.\) gets a variable value \(\omega_1^D = D \cdot \omega_1.\)

References
MODELING AND ANALYSIS OF SOME STABILIZATION SYSTEMS OF RADIUS FRACTURES

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ABSTRACT: In vivo experimental analysis of the stabilization of human bone fractures involves many issues, thus a virtual simulation of the mechanical behavior of assembly bone-plate-screws is more accessible. The paper presents a study of modeling and numerical analysis of four stabilization systems consisting of Screw-type Locking Compression Plates. The objective of the numerical analysis was to determine areas of maximum deformations and stresses occurring in bone-stabilization system under the action of certain loads. Based on the results obtained by numerical analysis for different plates, different fixing conditions, different loads, and two fracture types a comparison was performed, and the most favorable one was selected for the considered fractures. Based on the conclusions developed from the carried out research design of new models of stabilization systems depending on the fracture type will be performed.

KEY WORDS: modeling, numerical analysis, radius fracture, stabilization system.

1. Introduction

The Screw-type Locking Compression Plates are widely used in orthopaedic surgery. In order to choose the appropriate implant and its corresponding fixation, some studies are necessary to be performed: fracture type and location (from radiographic images), dimensions and shapes (according to the fracture type and location), implant component materials (biocompatibility, mechanical characteristics), fabrication technology, theoretical analysis of stress and deformation distributions, laboratory testing (mechanical tests), and clinical tests.

According to Fracture and Dislocation Classification Compendium – 2007, developed by Orthopedic Trauma Association, the studied fractures were of type of Radius, diaphyseal, simple fracture of radius (22-A2), Oblique (22-A2.1), partial and total fracture [1]. These kinds of fractures are very common, the radius being the most commonly broken bone of the arm.

There are currently available on the market various Straight Screw-type Locking Compression Plates, such as: Synthes Locking Compression Plate (LCP) System that merges locking screw technology with conventional plating techniques [2], Straight Screw-type Locking Compression Plates for Upper Limbs of Suzhou Sunan Zimmered Medical Instrument Co., Ltd company [3], Ulna and Radius Locking Compression Plates of Jiangsu Jinlu Medical Instruments Co., Ltd company [4], LC-DCP (Ulna and radius) of Tianjin ZhengTian Medical Instrument Co., Ltd. company [5], Contourable Dual Compression Plate, Broad, Narrow, and Small of Zimmer company [6], etc. These plates are available in various shapes, having different lengths and screw number.

Generally, fixation with a single bone plate and 3-4 screws assures sufficient compression between the bone fragments in order to promote the osteosynthesis. The evaluation of stresses and strains distribution occurring in assembly bone-plate-screws can prevent the unexpected mechanical behavior changes or failure. Thus, a numerical analysis of the assembly bone-plate-screws based on Finite Element Method was developed.

The paper deals with Straight Screw-type Locking Compression Plates for radius fractures, having different shapes and different number of locking screws. The objective of this study consisted in geometrical modelling and analysis of biomechanical behaviour of
simple straight locking plates with screw fixation used for radius fracture fixation. Based on the results of numerical analysis, new models of plates and screws, for both distal, proximal, and diaphyseal fractures (simple or multifragmentary) will be analyzed.

2. Modeling of the stabilization systems

Due to multiple choices concerning the surgical plates used in long bone stabilization fractures, there were considered four stabilization systems of radius fractures. Each stabilization system consists in a metallic plate having five holes and screws. The plate can be curved in order to fit to the curvature of the radius bone, but it can fulfil its fixation functions on a plane area too.

![a. Plate po - screws assembly](image1)

![b. Plate pr1 - screws assembly](image2)

![c. Plate pr2 - screws assembly](image3)

![d. Plate ps - screws assembly](image4)

**Fig. 1. Designed stabilization systems**

The geometrical modeling of the stabilization systems involves two different aspects of modeling: design of the anatomical elements and design of the mechanical elements.

Using Part module of the Solid Edge environment, both the anatomical and mechanical elements were modeled.

In figure 1 are presented the four stabilization systems, where the plates are coded by po (figure 1.a), pr1 (figure 1.b), pr2 (figure 1.c), and ps (figure 1.d).

To compare the biomechanical behaviour, the plates were designed to have the same overall dimensions (100 mm length, 10 mm width, and 2 mm thickness) and number of holes (five elongated holes) using the same locking screw type. Each plate has five elongated holes of 2.5 mm radius and 7 mm length. Also, each hole has a bevel of 0.75x1 mm diameter for a
better positioning of the screw. The S5 screw type has the external diameter of the thread of Ø 5 mm; the screw head has a conical shape and cross slot to allow the screwing into the bone.

3. Numerical analysis of the stabilization systems

Finite Element Analysis (FEA) is a method developed to compute a real model in a mathematical form for a better understanding of a highly complex problem [7], [8], [9]. The geometric structure of the model is defined as a finite number of simple elements composing a mesh. The analysis accuracy is strongly dependent on the number of finite elements composing the structure.

Having the model of the assembly bone-plate-screws, a simulation of the biomechanical behavior, using static structural module of the ANSYS Workbench environment V11, was developed.

The objective of this numerical analysis was to determine areas of maximum stress occurring into the assembly bone-stabilization system under the action of certain loads. The studies were individually performed for each stabilization system, by following the same steps and using the same loading and constrain conditions. Based on the results obtained by numerical analysis for different plates, different fixing conditions, and different loads, a comparison was performed, and the most favorable one was selected for the considered fracture (partial and total fractures).

The analysis started by importing the CAD model and declaring the material properties for each element of the assembly. The chosen materials were cortical bone for the radius, and titanium for the fixation screws and implant plates. All the material properties were chosen from ANSYS module, being essential and sufficient for this type of evaluation.

The first step of the analysis (allocation of the material properties) being completed, the mechanical contacts between the assembly’s elements were manually declared. There were considered the following contacts: plate-bone, screw-bone, and plate-screw (figure 2).

![Fig. 2. Contacts between the assembly components](image)

The contact setting was followed by the mesh structure generation (figure 3). This was automatically generated using tetrahedron elements of different sizes, and local refinement (implant area) factor 2.

In order to develop the static structural analysis, the assembly was fixed using a fixed support at the distal end of the radius. The considered loads resulted by applying a tensile force having different values (25 N, 50 N, 75 N, and 100 N), torsion moment of 20 Nm at the proximal end of radius, and screw tightening force of 10 N for each screw (figure 4). Each plate was fixed on the bone with three screws (figure 4).
Based on numerical analysis, a comparative analysis of mechanical behaviour of proposed stabilization systems was performed. There were considered two cases: total and partial fracture of the radius. Thus, stress and deformation distributions in assembly bone-stabilization system were determined [10].

As examples, in the following figures are presented the FEA results for pol assembly. Thus, the following figures illustrate: figure 5 - total deformation; figure 6 - equivalent stress; figure 7 - normal stress; figure 8 - shear stress.

Figure 5 illustrates that total deformations are lower for partial fracture than in case of total fracture. Total deformation increases with increasing of tensile strength in case of partial fracture and decreases in case of total fracture.

It may be noted that values of equivalent stress (figure 6) in case of total fracture of the radius are almost the same for any tensile force, while the values of equivalent stress in case of partial fracture decrease with force increasing.
The results indicate that normal stress (figure 7) has almost the same value in case of partial fracture and decreases into total fracture case with increasing of force. Normal stress is higher for total fracture than partial fracture.

The shear stress (figure 8) has almost the same value in case of partial fracture and decreases in total fracture with increasing of force.

In figures 9, 10, 11 and 12 it can be observed the areas with maximum values for: total deformation, equivalent stress, normal stress and shear stress respectively. All the examples presented in figures 9, 10, 11 and 12 correspond to the total fracture case.

4. Conclusions

Geometrical modeling of the Straight Screw-type Locking Compression Plates does not involve special issues. These first constructive solutions of the stabilization systems are simple, designed to validate the numerical analysis and then the experimental tests.

The numerical analysis evidences that the results (total deformation, equivalent stress, normal stress, and shear stress) for the partial fracture of radius bone are smaller than the corresponding values for the total fracture.

In case of total deformation the maximum value is recorded at the distal end of radius.
The values obtained for partial fracture are almost double comparing with the corresponding values in case of total fracture.

It can be noticed that the maximum values of equivalent stress are registered at the contact between the screw and bone plate and in the fracture area of the plate. In this case the maximum values obtained for total fracture drop with an order of magnitude in comparison with the partial fracture case.

The normal stress values obtained for partial fracture are also with an order of magnitude higher than the ones obtained for the total radius fracture. The areas where the normal stresses have maximum values are at the screw-plate contact.

The maximum values of shear stress appear at the screw-plate contact, and in the fracture area around the holes. The maximum values registered for partial fracture are approximately four times higher than those obtain for the total fracture but not greater than the admissible maximum values.

Experience and conclusions developed from the carried out research will be the basis for further studies that will follow:
- design of new models of bone plates having different shapes and dimensions, and screws, depending on the fracture type;
- comparative numerical analyses of new stabilization systems having different fixing conditions;
- experimental tests, taking into account different fracture types, stabilization systems, and loads.

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