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FRICTION IN THE KWE 15 LINEAR BALL RECIRCULATING GUIDEWAY. EXPERIMENTAL VALIDATIONS FOR UNLOADED CARRIAGE

Alexandru Cristian BUDEL, Vasile Ciprian STAMATE, Mihaela Rodica BĂLAN, Dumitru OLARU

Abstract: *An analytical friction forces model for a ball recirculating linear guideway with four contact points has been validated by experiments. The model was validated for a linear ball recirculating guideway type INA KWE 15 operating with linear speed of carriage between 1 to 10 mm/sec and with load acting on carriage between zero to 50N. The experiments were carried out on the linear table of the Tribometer CETR UMT2 for the unloaded carriage. Also, was determined by experiments the total recirculating forces acting on the balls. Important variations of the friction force caused by the variation of the force generated in the recirculation process of the balls were evidenced. For unloaded carriage,the analytical model was validated by experiments.*

Key words: *Friction force, ball recirculation linear system, kinematics of the balls, dynamic of the balls, lubrication, tribometer.*

1. INTRODUCTION

Linear ball recirculating guideway have a lot of advantages compared to conventional sliding guides and are used in many applications which need high precision for linear displacements (robots, machine tools, etc). In the motion of the carriage a tangential force is developed as result of some power loss sources: rolling and sliding friction on contact ellipses between balls and the races, loss generated by the friction between the balls, loss generated by the friction between the balls and the recirculating race, loss generated by friction with lubricant. In the last period Olaru et. al.[1,2,3,4] elaborated some complex analytical models to evaluate the total friction force in linear ball recirculating guideway with two or four point contacts applied for INA types KUVE 25 V1 and KUE 35 V2 operating at high loads. The recirculating linear guideway type KWE 15 have four contact points between a ball and the races and the analytical model for friction force need a complex analysis of the balls kinematics. So, depending of the normal loads in the ball–races contacts on the contact ellipses can be developed rolling and pivoting motion with important increase of the power losses or only rolling motion with lower power losses.

In the present paper the authors adapted the analytical models of kinematics and dynamics for KWE 15 linear guidance system and a lot of experiments to validate the analytical models were conducted.

2. ANALYTICAL KINEMATICS AND FRICTION RESULTS

2.1 Kinematics model and results

In Fig. 1 the position of a ball in a four-point contacts linear system, type KWE 15 is presented. The ball is in contact with the carriage and guide in the two contact ellipses C1, C2 and G1, G2, respectively. Under the load **Fy** the normal loads on the four contacts are: Q1 on the contacts C1, G1 and Q2 on the contact C2, G2. The angle α is $\pi/4$ and the position of the angular speed of the ball $\boldsymbol{\beta}$ have values between zero (when the normal loads Q1 and Q2 are equals) and $\pi/4$ when the normal load Q2 = 0 (by increasing of the force Fy).

For imposed loads Q1 and Q2 and for imposed linear speed of the carriage $\boldsymbol{v}$ the angular speed of the ball ω_b and the angular position β can be determined according to the minimum value of the total power loss generated by sliding of the ball on the two races. As presented in [3,5], the total power loss on contact ellipses C1 and C2 can be expressed as a complex function having two variables: β and ω_b.

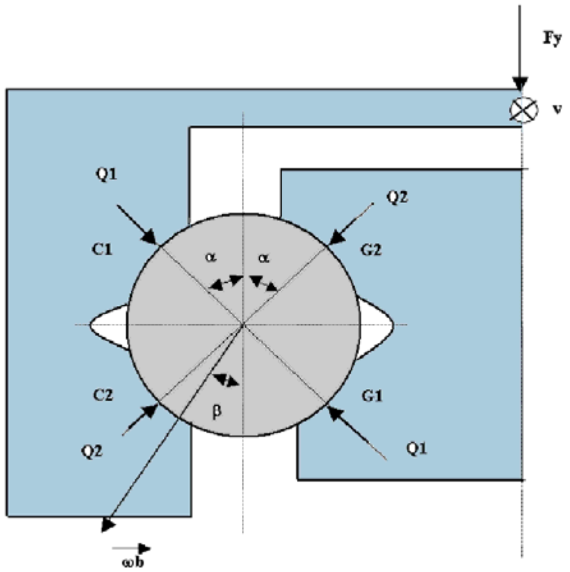


Fig. 1 The kinematics of a ball in KWE 15 linear guidance system

Fig. 2 presents the variation of total power loss $PS = PS(\beta, \omega b)$ for normal load Q1 = Q2 = 5N (only the preload when Fy = 0), linear speed v=0.01m/s and an average friction coefficient on the contact ellipses $\mu = 0.11$.

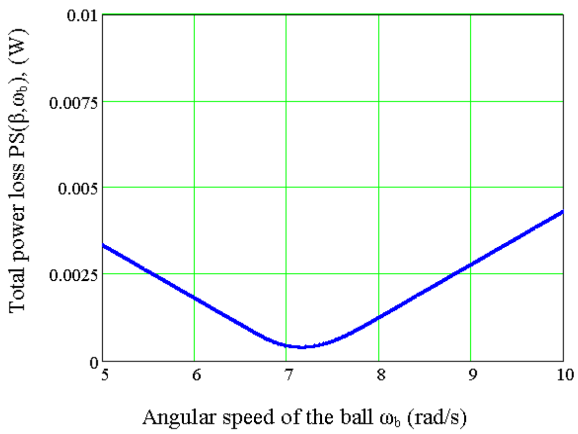


Fig. 2 Variation of the total power loss as function of angular speed ω_b for $\beta=0$ (no load Fy)

It can be see that a minimum power loss is obtained for angular speed of the ball ω_b= 7.18 rad/s. For the contact ellipse C1 the sliding speed distribution are presented in Fig. 3 and suggest the pivoting motion. The similar sliding speed is obtained on the contact ellipse C2.

By increasing the load Fy, the normal loads Q1 increase and the normal loads Q2 decrease. For a normal load Q1=10N the normal load Q2 becomes null.

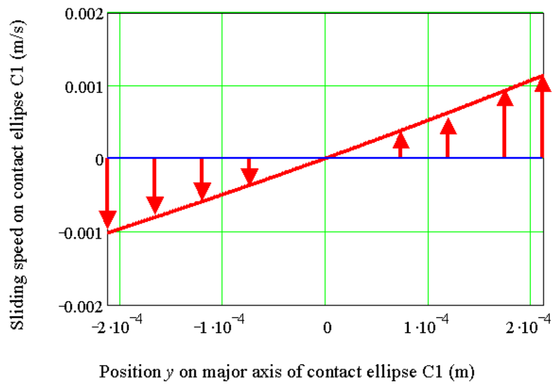


Fig. 3 Variation of the sliding speed on contact ellipse C1 for $\beta=0$

As a consequence, the angle β increases from zero to $\pi/4$ and angular speed of the ball decreases from 7.18 rad/s to 5.08 rad/s. In Fig. 4 it can be observed the variation of the total power loss for Q1=10N, Q2=0N and $\beta = \pi/4$.

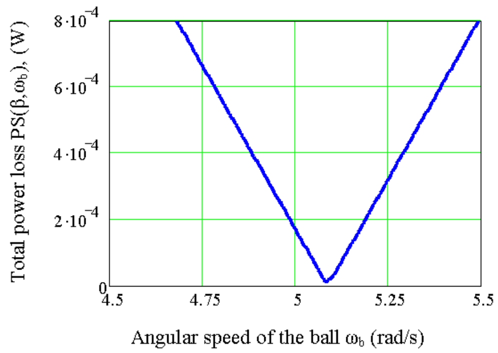


Fig. 4 Variation of total power loss as function of angular speed ω_b for $\beta = \pi/4$

The variation of the sliding speed on the contact ellipse C1 for $\beta = \pi/4$ and ω_b=5.08 rad/s is presented in Fig. 5.

It can be observe that on contact ellipse C1 the ball have also sliding speed with two line having pure rolling, but the maximum sliding speed is about two order of magnitude smaller that in the case of β=0. Also, the total minimum power loss when angle $\beta = \pi/4$ is

$1.4.10^{-5}$ Watts and for β=0 the total minimum power loss is 4.10^{-4} Watts.

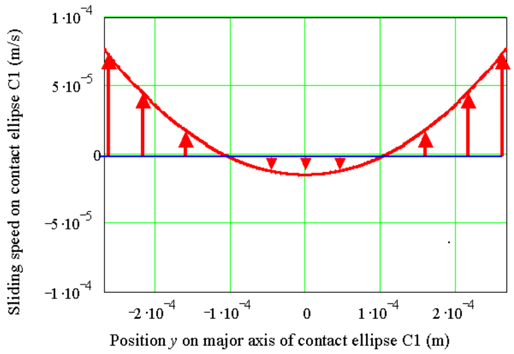


Fig. 5 Variation of the sliding speed on contact ellipse C1 for $\beta = \pi/4$

2.2 Dynamic model and results

Based on the dynamic model developed in [1,2,3,4] the total friction force developed between the loaded balls and the guide was determined. The linear ball recirculating guideway type INA KWE 15 has 9 loaded balls with diameter of 3.983mm for each recirculating row. For a linear speed of the carriage having 0.01m/s, the lubrication regime between balls and races is limit and an average friction coefficient on the contact ellipses $\mu = 0.11$ was imposed. In the theoretical model the total friction force between the all loaded balls and guide FC includes the contact forces between two successive balls, Fb. These forces are depending of the friction between balls and recirculating race and have an important influence for low loads Q1 and Q2. So, in Fig.6 the variation of the total friction force FC as function of the force Fb for Q1=Q2=5N is presented.

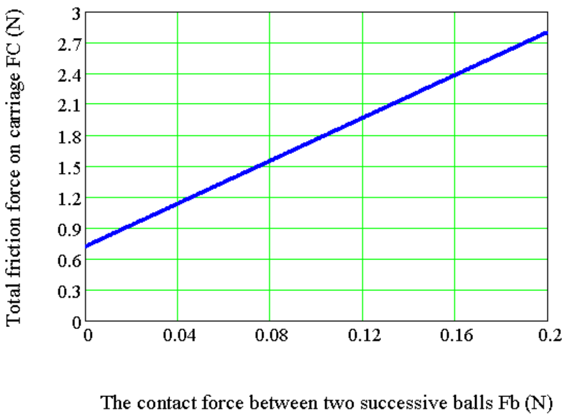


Fig.6 The variation of the total friction force FC with force Fb for Q1=Q2=5N.

If the force Fb is neglected, the total friction force for Q1= Q2 =5N (unloaded carriage) have a value of 0.75N. If the force Fb increases to 0.2N the total friction force FC can increase to about 2.7 N. In the experimental results it can be observed important variations of the total friction force FC caused by the variations of the force Fb.

If the normal load Q1=10N and normal load Q2=0N, the total friction force on carriage Fc decreases as result of absence the pivoting motion. The variation of the total friction force FC with force Fb for Q1=10N and Q2=0N is presented in Fig. 7.

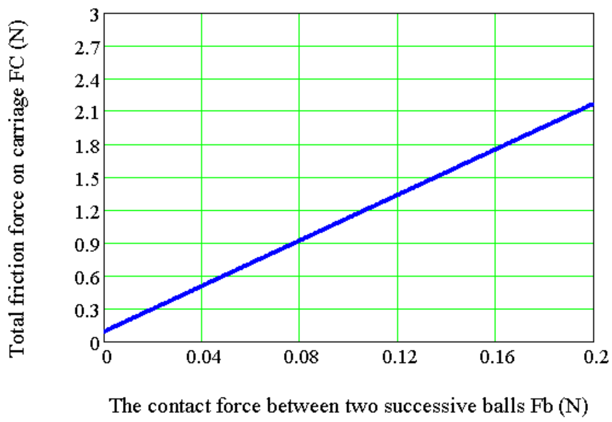


Fig.7 The variation of the total friction force FC with force Fb for Q1=10N and Q2=0N.

3. EXPERIMENTAL RESULTS

3.1 Experimental equipments and procedure

The experiments were conducted in the Microtribology Laboratory from Mechanical Engineering Faculty of Iasi by using the Tribometer CETR UMT 2 and a linear ball recirculating guideway type INA KWE 15. The guide of the system was monted on the linear table of the tribometer. With the pin and force sensor was determined the total friction force FC when the table of the tribometer realized linear displacements with speed between 0.001m/s to 0.01 m/s. A general presentation of the Tribometer CETR UMT 2 with the linear guidance KWE 14 mounted on the linear table is presented in Fig. 8. In Fig. 9 is presented in detail the linear guidance system KWE 15 mounted on the linear table of the tribometer.

The experiments were realized by moving the guide mounted on the linear table of the tribometer covering a distance of 60mm in positive and negative direction.

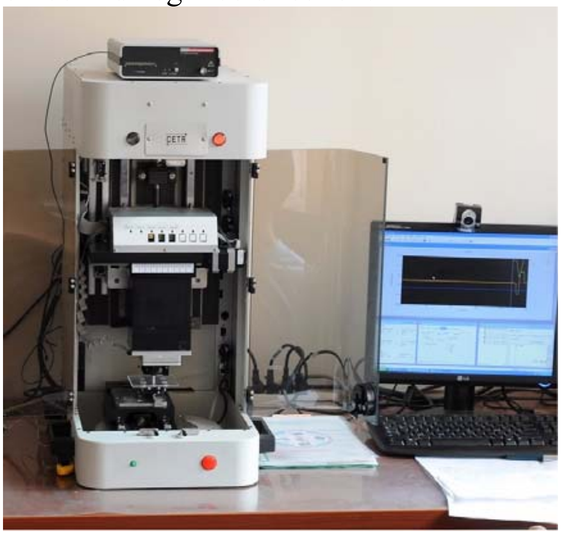


Fig. 8 General view of the Tribometer CETR UMT 2 and linear guidance KWE 15

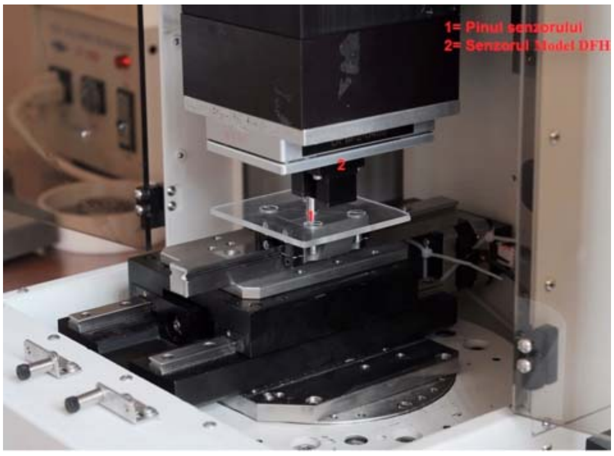


Fig. 9 Detail of the linear guidance KWE 15 mounted on the linear table of the Tribometer

3.2 Experimental results

The experiments were realized without force Fy to determine the internal preload force and to evidence the influence of the force Fb on total friction force.

According to the tribometer's soft the force Fx corresponds to the total friction force acting on guide raceway FC and have positive and negative sign depending of the direction of movement. In Fig. 10 a sequence of the friction force Fx with negative and positive values depending of the motion direction is presented.

To evidence the variation of the friction force for all sliding distance in a direction and in opposite direction was preferred to be presented the diagrams type Fx – X, where X is the sliding distance of the table.

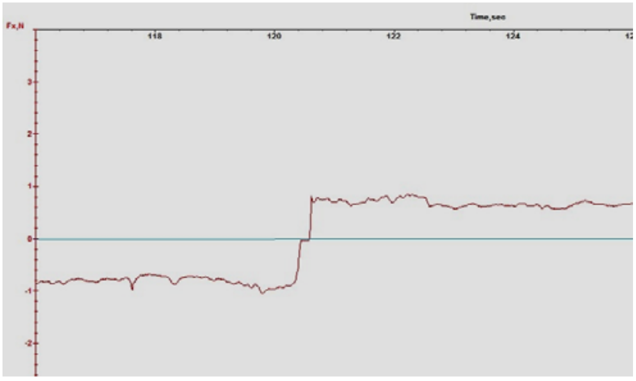
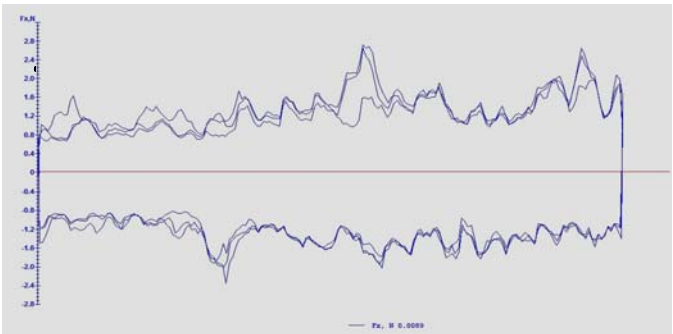
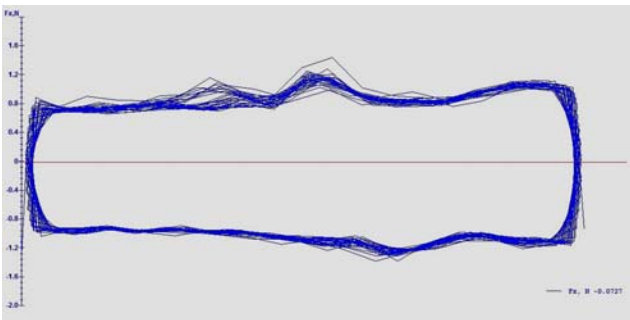


Fig. 10 The variation of the total friction force with time for linear speed v=0.001m/s and Fy=0N

In Fig. 11 are presented the variations of the total friction force FC (force Fx) with sliding distance X for two linear speed of the table: 1mm/s and 10mm/s.



(a)

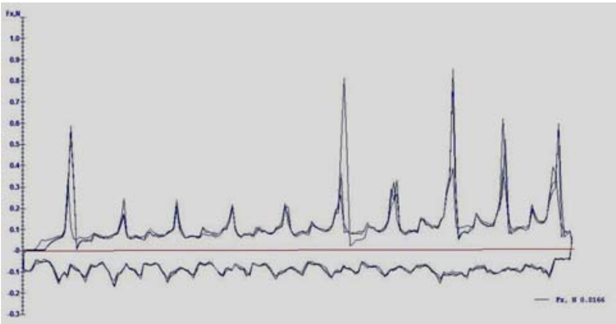


(b)

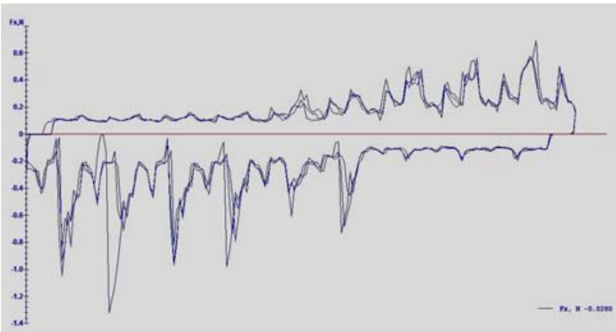
Fig. 11 The variation of the total friction force for linear speed v =1mm/s (a), v =10 mm/s (b) and for Fy=0N

It can be observed that the minimum friction force FC is about 0.8 N that means of a preload Q1=Q2=5N and a contact force Fb=0. During all sliding space it can be observed important variations of the friction force to maximum 2.8 N at the speed of 1mm/s. These variations are caused by the variations of the contact forces between balls Fb.

By using an original methodology (not presented in this paper) were determined the variation of the total recirculation force F_{rec} of the balls on both sides of the carriage. In Fig. 12- a and 12-b are presented the variations of the diagrams type force F_{rec} and distance X in one direction and opposite direction of motion for a speed of 1mm/s, for the two recirculating rows A and B of the carriage.



(a)

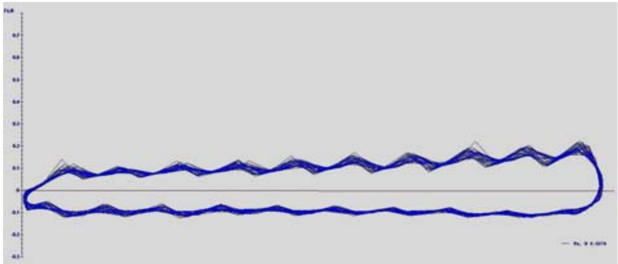


(b)

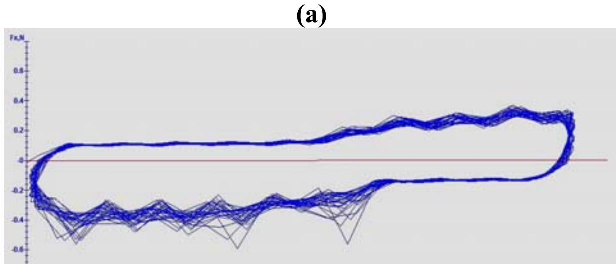
Fig. 12 The variation of the total recirculating force F_{rec} for recirculating row A (a) and for recirculating row B (b) and for a linear speed v =1mm/s

On both recirculating rows the total recirculating force F_{rec} has important variations from 0.1N to 1.3N. We considered in our theoretical model that the force between two successive balls in contact $Fb = F_{rec}/z$, where z is the number of loaded balls. For our experiments, z = 9 and the force Fb varied between 0.01N to 0.13N. According to the diagram from Fig. 6, if Fb have a variation between 0.01N to 0.14 N, the total friction force FC on carriage have a variation between 0.9N to 2.15N, values observed in the measurements presented in Fig.11-a.

By increasing the speed it can be observed a decrease of the variations in friction force, so that for speed of 10 mm/s the maximum force not exceeds 1.3N. It can be explained by decreasing of the total recirculating forces at 10 mm/s as can be observed in the diagrams from Fig.13- a and Fig.13- b.



(a)



(b)

Fig. 13 The variation of the total recirculating force F_{rec} for recirculating row A (a) and for recirculating row B(b) and for a linear speed v =10 mm/s

At the speed of 10 mm/s on both recirculating rows the total recirculating force F_{rec} has small variations from 0.1N to 0.6N that means values for Fb between 0.01N and 0.07N. According to theoretical model presented in Fig. 6, the total friction force Fc have a variations between 0.8N to 1.5 N, that is in good correlation with the values obtained by experiments and presented in Fig.11-b.

4. CONCLUSIONS

An analytical friction forces model for a ball recirculating linear guideway with four contact points has been validated by experiments.

The experiments were realized with a linear ball recirculating guideway type INA KWE 15 operating with linear speed of carriage between

1 to 10 mm/sec and without the load on carriage.

Important variations of the friction force caused by the variation of the force generated in the recirculation process of the balls were evidenced.

The obtained values for unload carriage was in good correlation with the analytical model, dominant power loss being generated by the pivoting motion of the balls.

5. AKNOWLEGEMENT

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FRECAREA ÎN GHIDAJE CU ROSTOGOLIRE CU BILE RECIRCULABILE TIP KWE 15. VALIDĂRI EXPERIMENTALE

Rezumat: Lucrarea prezintă validarea experimentală a unui model analitic dezvoltat pentru calculul forței de frecare în ghidaje de rostogolire cu bile recirculabile. Validarea a fost făcută pe ghidajul de tip INA KWE 15 în condițiile unor viteze de translație a căruciorului cuprinse între 1 – 10 mm/s şi fără sarcină aplicată pe cărucior, la contactele dintre bile şi căile de ghidare existând mişcare de rostogolire combinată cu mişcare de pivotare. Experimentele au fost realizate utilizând Tribometrul CETR UMT-2 din dotarea Laboratorului de Microtribologie a Facultății de Mecanică din Iaşi. Au fost puse în evidență importante variații ale forței de frecare determinate experimental şi puse în corelație, pe baza modelului analitic, cu forțele dezvoltate între bile în procesul de recirculare. Au fost determinate experimental forțele totale de recirculare ale bilelor pe cele două canale ale căruciorului care au stat la baza modelului analitic

Alexandru Cristian BUDEL, Drd. Ing., Department of Mechanical Engineering, Mechatronics and Robotics, Mechanical Engineering Faculty, Technical University "Gheorghe Asachi" Iaşi;

Vasile Ciprian STAMATE, As, Dr. Ing., Department of Mechanical Engineering, Mechatronics and Robotics, Mechanical Engineering Faculty, Technical University "Gheorghe Asachi" Iaşi;

Mihaela Rodica BĂLAN, Sl. Dr. Ing., Department of Mechanical Engineering, Mechatronics and Robotics, Mechanical Engineering Faculty, Technical University "Gheorghe Asachi" Iaşi;

Dumitru OLARU, Prof. Dr. Ing., Department of Mechanical Engineering, Mechatronics and Robotics, Mechanical Engineering Faculty, Technical University "Gheorghe Asachi" Iaşi, dolaru@mail.tuiasi.ro, dumitru_olaru@yahoo.com, tel: 0232 232337.