FINITE ELEMENT ANALYSIS OF A SLIDING BEARING FROM BASIS TRANSLATION MODULE OF A ROBOT

ПРИМЕНЕНИЕ МЕТОДА КОНЕЧНЫХ ЭЛЕМЕНТОВ ДЛЯ АНАЛИЗА ПОДШИПНИКОВ СКОЛЬЖЕНИЯ В СДВИГОВОМ МОДУЛЬНОМ ОТСЕКЕ РОБОТА.

Prof. dr. eng. Davidescu A.1, Assist. Prof. dr. eng. Sticlaru C.[1], Lecturer dr. eng. Mateaş M.[1],
Faculty of Mechanical Engineering [1]– "Politehnica University of Timişoara, Romania
E-mail: arjana.davidescu@mec.utt.ro; E-mail: carmen.sticlaru@mec.utt.ro; E-mail: marius.mateas@mec.utt.ro.

Abstract: *The paper presents some finite element studies of a sliding bearing which belongs to basis translation module of a robot. Different stroke lengths and temperatures are investigated. The stress and strain state are revealed for these scenarios, emphasizing the maximum deformation of the slider. This study is useful for studying the robot accuracy.*

Keywords*:sliding bearing, finite element method, stress and strain state, robot accuracy*.

1. Introduction

Sliding bearings are those in which two or more elements in the bearing assembly slide over one another. The properties of the bearing are determined by the coefficient of friction of the two materials upon one another and the loads transferred to the bearing. These properties can be aided by the use of lubricants, generally oil or grease. The lubrication does not totally eliminate contact between the surfaces, and this is the distinguishing factor between sliding-contact and non-contact bearings.
Among all the mechanical motions this is the trickiest and most potentially unreliable. It should not be attempted without adequate materials and fabrication techniques. Guided sliding members tend to cock and jam. Wear causes the situation to become increasingly worse. Guiding members should be very smooth, hard, and preferably even sized cylindrical shafts. Sliding hubs should have closely fitting bores with just enough clearance for lubrication (0.001" per inch of shaft diameter). Materials should be steel for shafts, and either steel or hard brass for the bores. Never use aluminum or wood for sliding members. Both materials cause stick-slip performance and frequently tend to jam, wear badly, and seize easily.
The difficulties of insuring reliable sliding motions can never be emphasized enough. The failure of most mechanical functions can often be traced to sliding linear members [1, 4, 5].
Sliding contacts at bearings, running surfaces of cylinders or cam transmissions have an essential influence on the mechanical operating conditions of machines, combustion engines or turbines. High value is placed on the construction of compact machines and, therefore, improved thermal and mechanical efficiency is required. This causes a saturation of many machine components, for example, sliding bearings. Under unfavorable circumstances, the minimal lubricating gap becomes so small that a complete hydrodynamic separation of shaft and bearing is no longer guaranteed. Friction and wear increase quickly, leading finally to a failure of the bearing. The failure of a bearing in a ship motor may represent a threat to the machine, ship and environment, as well as to human lives. Failure-free running machines demand efficient and reliable monitoring systems, which can report on the current condition of the bearing arrangement while in operation.
Due to the fact that an industrial robot is considered as a hyper system it is obvious that many factors compromise quality indicators, such as accuracy. One can summarise this situation as follows, in fig.1
One of the most frequent causes for diminished accuracy is deformation of the robot's mechanical elements [2]. This is caused not only by load but also by temperature. Let's presume that we look at the translation module of a robot. This module consists of an interface for the others modules such as additional rotations and translations and two slides on which the interface slides. In time, due to poor lubrication and load, the slides becomes warm, about 70 Celsius degrees in 8 hours. This conjunction of factors will produce deformation of the slides and the coordinates of the mass centrums will change. The final effect will be a new position for the characteristic point of the robot with serious implication on accuracy.

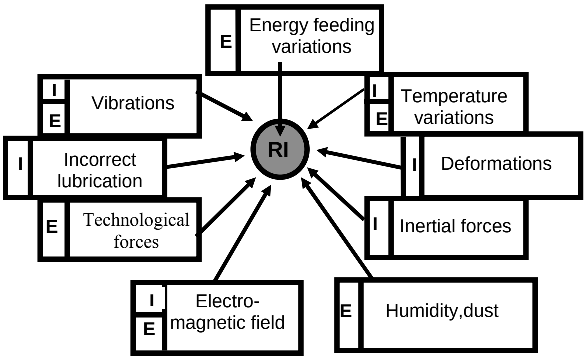


Fig1. The influence of the internal and external factors on robot's accuracy

By means of temperature and deformation monitoring and by means of preventive simulation one can achieve better accuracy and finally better quality of the robotized operations.
The industrial robot can be seen as an complex thermal system characterised by the interconnection between thermal and quality indicators.From termical point of view, a robot is characterized by two factors: the thermal stability and the thermal behavior. The thermal stability of a robots shows how the geometrical parameters are mainteined during thermic changes.
The thermal behaviour shows how the industrial robot respond to direct heat sorces action on his mechanical system.
The interconnection between thermal and geometrical factors is presented in fig. 2.

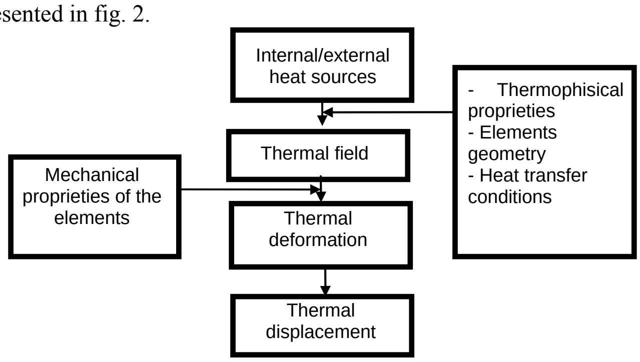


Fig 2. The influence of temperature

Researches show that the thermal deformation is responsable for 10% of the robot situation accuracy.
There for it is important to estimate the robot behavior through simulation, when it is subdue to load and heat sources. Simulation input data can be experimentally determinated.
The main reason for this research was to study the influence of temperature upon the accuracy of the robot.

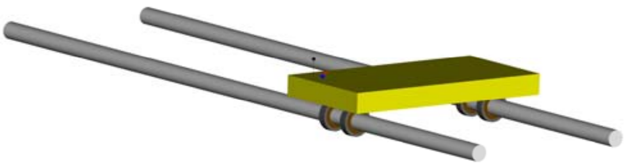
2. *The finite element model*

The kinematic structure of the investigated robot is TTT. The basis joint was investigated.
The slider temperature was measured during functionning, with 8 termocouples. One of the slider is lubricated and the other is not lubricated. After 300 strokes, the temperature of the two slider is different. The non-lubricated one has a medium temperature of 70 Celsius degrees and the other one, only 40 Celsius degrees. One data set of the experimental results is presented in table 1 [2].

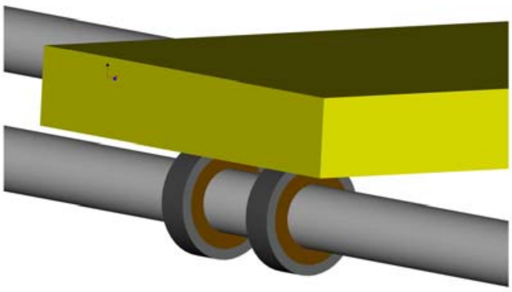
Table 1. Experimental temperature data

No.	Time [min]	Temperature [˚ C]
1.	0	37.8
2	5	38.5
3.	10	39.2
4.	15	40.5
5.	20	42.3
6.	25	44.8
7.	30	50.5
8.	35	52.7
9.	40	54.5
10.	45	58.7
11.	50	64.5
12	55	68.6
13.	60	72.3

The 3D model was developed in ProEngineer and it is presented in figure 3.



a.



b.

Fig. 3 The whole 3D model of the kinematic joint (a) and a slider hub detail (b)

All parts are made of steel except the inner slider hub, which is made of bronze (see fig 3 b). The 3D model was imported in Ansys in order to develop the finite element analysis. The sliding length is 300 mm.
Some partitions have been made so that the deformation of the central point from the sliding assembly can be depicted. Different analysis were run considering different working conditions.
A proper functioning is correlated to lubrification conditions – if the lubricants are not suited to working parameters (weight, roughness, sliding velocity), the friction coefficient increases significantely. This phenomenon influences the temperature of the contact region between the sliding hub and sliding guide.
It can seen that the maximum registered temperature in the experimental study (table 1) is 70 ˚C for an unlubrificated sliding bearing. The lubrification conditions for the two sliders can be different during the robot functioning cicle.
For these reasons, two types of analisys werw run:

- similar lubrification conditions for both robot sliders; a temperature range from 30˚C to 70˚C with 10˚C step was investigated (ambient temperature - 22˚C);
- different lubrification conditios; one slider has a greater friction coefficient due to insufficient lubrification that increases the hub slider temperature (range of 40˚C - 70˚C), the other one has good lubrification (aprox. 40˚C).

The environment of the finite element model consists of:

- fixed support – on the extremities of the slider bars (except the working lenght of the robot plate);
- pressure load (1 MPa)– on the upper face of the robot plate;
- temperature (parameter - in range of 30˚C to 70˚C); different lubrification condition was simulated by different temperatures imposed to the inner sliding hubs. In the first case, the imposed temperatures were the same for both sliding bars (up to non lubricated sliders - 70˚C). In the second finite element analysis types, the correct lubricated slider has aprox. 40 Celsius degrees and the non-lubricated one has a range of temperature up to 70 Celsius degrees;
- temperature dependent convection was imposed on all surfaces in contact with air.

Convection is related to heat flux by use of Newton's law of cooling [3]:

$$q/A = h(t_s - t_f)$$

where:

- q/A is heat flux out of the surface (calculated within the application)
- h is the film coefficient (you provide)
- t_s is the temperature on the surface (calculated within the application)
- t_f is the bulk fluid temperature (you provide)

When the fluid temperature exceeds surface temperature, energy flows into a part. When the surface temperature exceeds the fluid temperature, a part loses energy.
If you select multiple surfaces when defining convection, the same bulk fluid temperature and film coefficient is applied to all selected surfaces.

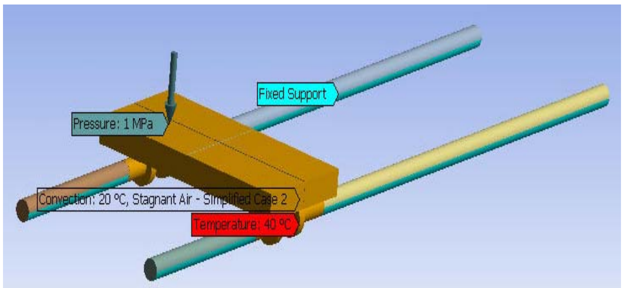
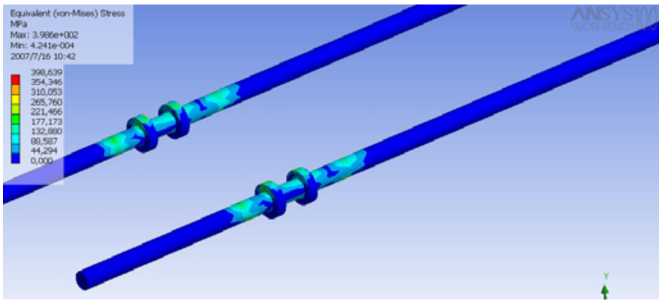


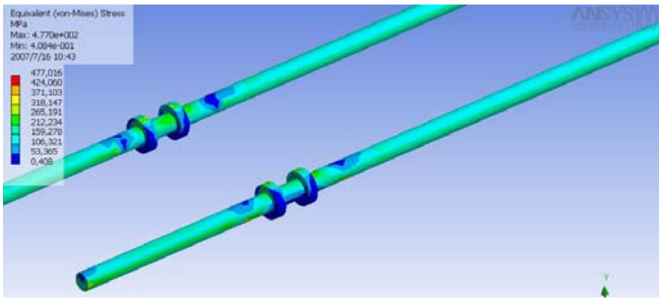
Fig. 4. The environment for the sliding module

3. *Results and conclusions*

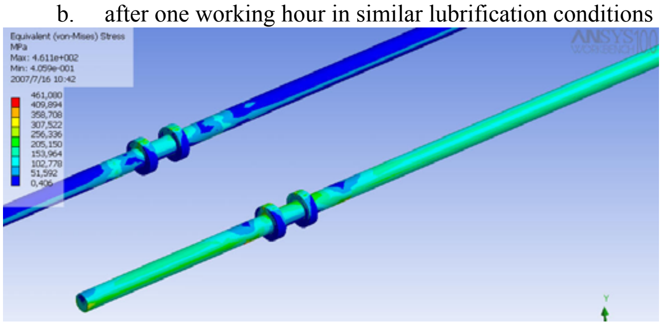
The equivalent von Mises stress state can be seen in figure 5. The most unfavourable case is the one when the highest values of stresses are registreted, which correspond to non lubricated contact between slider bars and hubs. As temperature increases the stress state map looks different:
– when sliders are correctly lubricated the stress has effect on the sliding length of the bars;
- when lubrification problems occur, the stress influences the whole length of the bars.
For the range of temperature experimentaly obtained, the maximum values of equivalent von Mises stress increase up to 15% from the case of well lubricated slider at the stroke beginning to non lubricated slider after one hour working.



a. at start



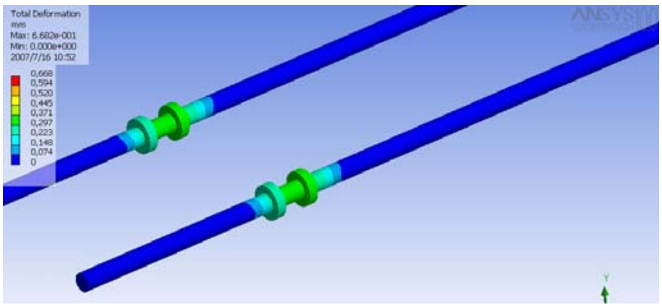
b. after one working hour in similar lubrification conditions



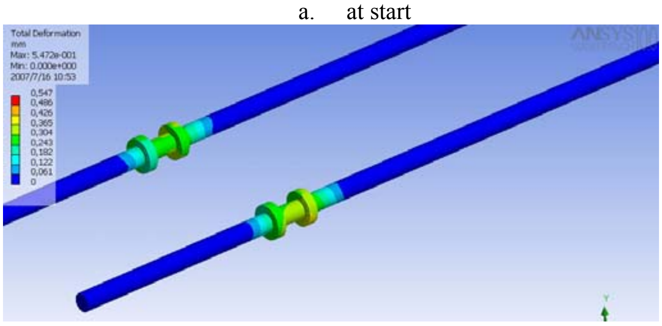
c. after one working hour in different lubrification conditions

Fig. 5. Equivalent von Mises stress state

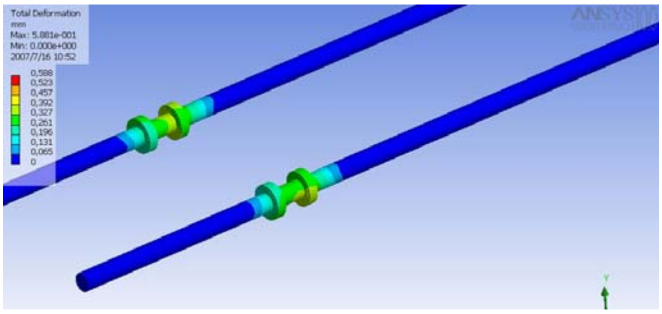
Figure 6 presents the total deformation map from the most significant cases depicted from the run analysis. The total deformation map is similar for all studied environments. It can be seen that the maximum value occurs at the start point. After 300 strokes, when the lubrification conditions alter, the temperature increases, the total deformations decrease. This phenomenon can be explained by volumetric dilatation of the metallic structure.



a. at start



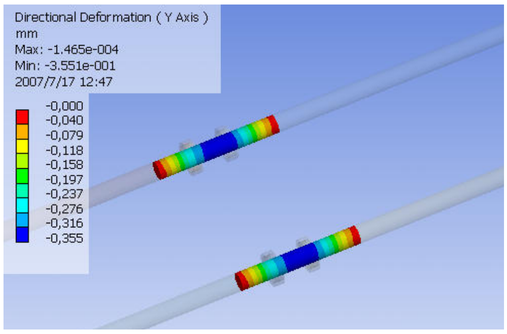
b. after one working hour in similar lubrification conditions



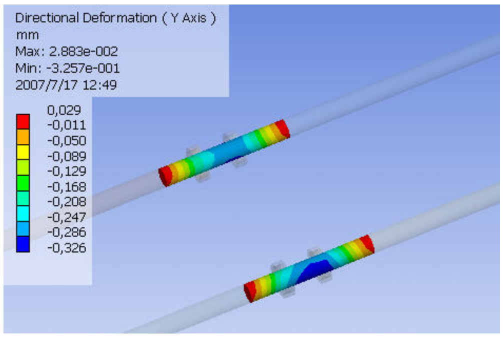
c. after one working hour in different lubrification conditions

Fig. 6. Total deformations map

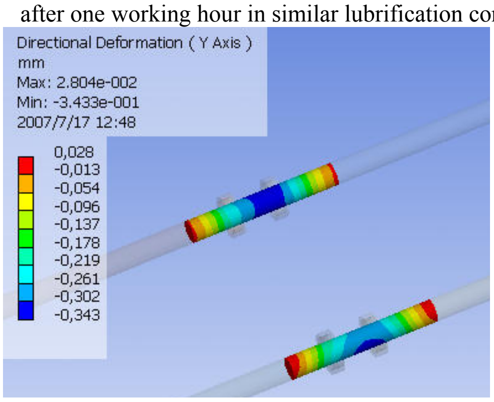
The vertical deformation of the sliding bar can be seen in figure 7. In order to emphasize the vertical deformation of the sliding bars, which influence the robot accuracy, the pictures present only the sliding length map.



a. at start



b. after one working hour in similar lubrification conditions



c. after one working hour in different lubrification conditions

Fig. 7. Directional deformation along vertical axis

The maximum value of vertical deformation appears at start point. From vertical deformation map it can be observed a symmetric displacement, that means a vertical translation for the characteristic point. For different lubricated bars, the symmetry of vertical displacement disappears. In this case the movement of the characteristic point became complex – the translation is accompanied by a rotation. The occurence of the rotation may have major implications upon robot accuracy, due to the distance between the characteristic point and the slider bars.

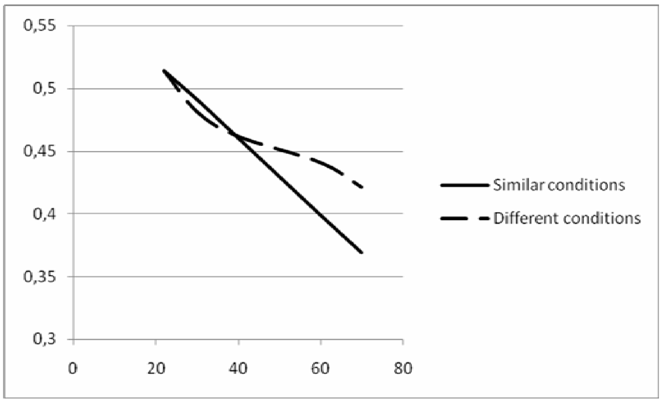


Fig. 8. Total deformation of the centrum mass versus temperature

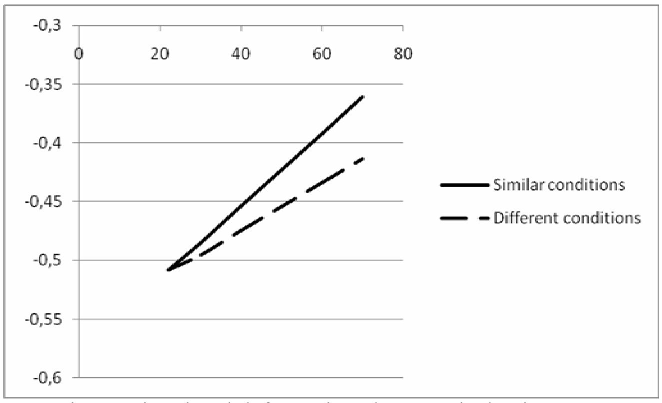


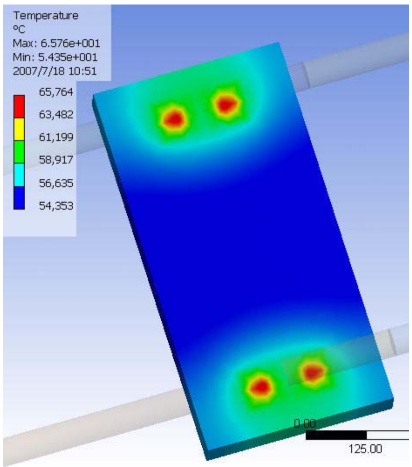
Fig. 9. Directional deformation along vertical axis versus temperature

All the results (total and vertical deformation) from FEM analysis are synthesized in figure 8 and 9. These graphics illustrate total deformations (fig. 8) and vertical ones (fig. 9) versus temperature, for similar and different conditions of slider bars lubrification. Both graphics present the deformations of the mass center of the sliding plate. It can be seen that the total deformation decreases as the temperature increases. This phenomenon can be explained by the volumetric dilatation of the assembly.

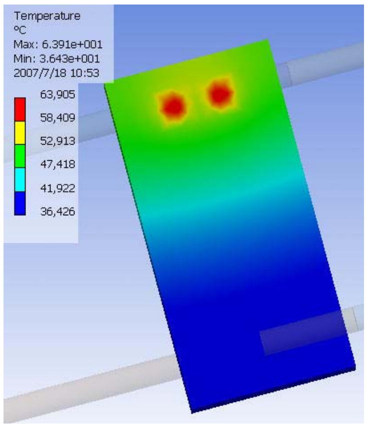
The decrease of vertical deformation has smaller values for similar condition of lubrification as against different condition due to the fact that the well lubricated slider bar preserves larger deformations caused by a lower working temperature.

In figure 10 are presented the temperature maps for the sliding plate. It can be observed the heat transfer for the sliding hub to the robot plate due to the sliding bearing friction.

In spite of smaller deformation values obtained for different lubrification conditions, the similar lubrification conditions are preferred. Even the lubrification condition are not suitable and the temperature increases, the vertical deformations are pure translations. When different conditions are involved, the translation is associated with a rotational component that amplifies the displacement of the robot characteristic point.



a. Similar conditions



b. Different conditions

Fig. 10. The temperature maps of the sliding plate after working one hour

Using thermal finite element method some important aspects from working sliding bearing can be reveald untill robot design process to increase it’s accuracy. The lubrification conditions are modifying during working period and some bad effects can be prevented.

An important conclusion of this research study is that a thermal finite element analysis is a very useful tool for simulate the working behaviour of a robot sliding bearing in order to depict it’s influence upon the robot accuracy.

4. References

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