ACTA TECHNICA CORVINIENSIS
– Bulletin of Engineering
Tome X [2017]
Fascicule 2 [April – June]
ISSN: 2067 – 3809

[1.]Jovan PAVLOVIĆ, [2.]Dragoslav JANOŠEVIĆ, [3.]Vesna JOVANOVIĆ

OPTIMIZATION OF DRIVE MECHANISM OF MOBILE MACHINES MANIPULATOR USING TRIBOLOGICAL CRITERIA

[1-3.] University of Niš, Faculty of Mechanical Engineering, Niš, SERBIA

Abstract: In paper is defined the optimization tribological criteria of the manipulators crank driving mechanisms of mobile machines. Criteria indicator is mechanical efficiency of driving mechanisms, which reflects the tribological loss power of machines driving system due to friction between the elements of kinematic pairs (joints) manipulator's driving mechanisms.
Keywords: driving mechanisms, optimization

INTRODUCTION

Manipulators of mobile machines (Figure 1) represent multisegment kinematic chains with segments, in the form of lever, which are connected rotary or translational joints of the first class. The last segment in the kinematic chain of manipulators are different tools by which perform the basic functions of the machine. Drive mechanisms of manipulator built kinematic pairs of manipulators who connected with hydrostatic actuators (hydro cylinders and hydro motors).

Most common mechanisms of manipulator of mobile machines are kinematic pairs, with relatively mobile L_i (Figure 1) and fixed segment L_{i-1}, and with two-way hydrocylinder c_i which is directly linked for segments of the kinematic pairs of mechanisms. With their transfer function, the drive mechanism of manipulator, input hydrostatic parameters of forces (flow and pressure) machine drive system, are transformed into outputs parameters of mechanical power in the form of angular velocity ω_i (Figure 1) and the required driving moment M_{pi} with which the mobile segment L_i becomes executive segment of the mechanisms with rotating motion.

The total transfer function mechanism depends on transformation and transmission parameters. Transformation parameters of the mechanism are diameter of the piston and diameter of the piston rod hydro cylinder. Transmission parameters of the mechanism are: initial and final kinematic length of the hydro cylinder and position coordinates of the center of joints in which the hydro cylinder linked for segments of the kinematic pairs of mechanisms.

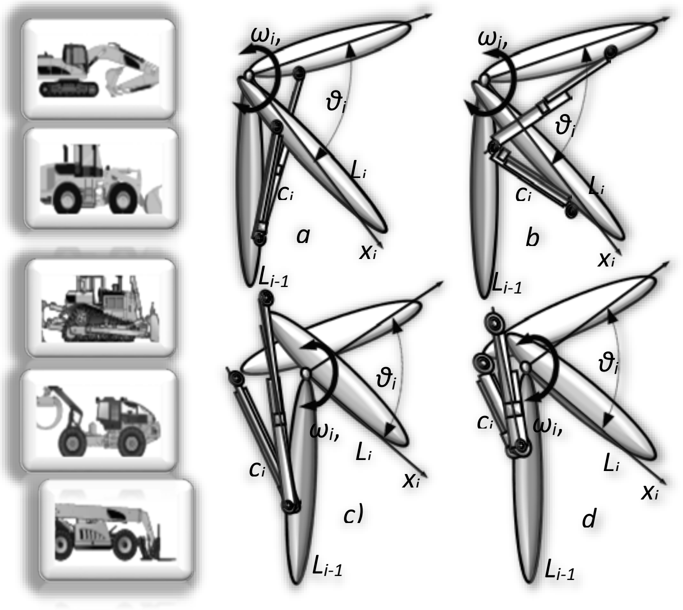

Figure 1. Possible variant solutions of the drives manipulators mobile machines

CRITERIAS OF OPTIMIZATION

The procedures synthesis the mechanisms of manipulators show that for the same given input hydrostatic parameters forces can define more variant solutions of mechanisms which have the same output parameters but different transformation and transmission parameters of their structural material.

For example, the same range angle θ_{io} (Figure 1) motion and drive moment M_{pi} executive segment of the mechanism can be achieved with the same transformation parameters (hydro cylinder same size) but different transmission parameters (Figure 1 a,b,c), where, in principle, an executive segment of the mechanism may be in the form of single arm lever (Figure 1 a,b) or the two-arm lever (Figure 1 a,b). Besides, variant solutions of mechanisms are possible with lower transformation and higher transmission parameters (Figure 1c) and vice versa, with more transformational and less transmission parameters (Figure 1d).

For selection the optimal solution driving mechanisms of mobile machines manipulators, from set of possible variant solutions, set up the basic objective function:

max . performance - min . power of machine, expressed the following criteria optimization [2][3]:

- $K_1=\max(F_m)$ - criterion of maximal functional dependence of all of the driving mechanisms manipulators, which expresses efficiency of machine functions through estimate harmonious mutual activities possible drive moments of mechanisms at negotiation the external loading of manipulator in the in the whole working area of machine,
- $K_2=\max(\eta_m)$ - tribological criteria defined on the basis of mechanical degree of usefulness drive mechanisms ηm, which reflects the tribological loss of power driving system machine because of friction between the elements of kinematic pairs (joints) of driving mechanisms manipulators,
- $K_3=\max(m_i)$ - the criteria of minimum mass mi segments of kinematic pairs driving mechanisms of manipulators expressed by general conditions factor of nominal mass, which is defined according to the criteria stress state segments of mechanisms,
- $K_4=\max(m_{ci})$ - criteria of minimum mass mci actuator (hydrocylinder) driving mechanisms of manipulators,
- $K_5=\max(m_{si})$ - criteria of minimum mass msi segments of kinematic pairs (joints) driving mechanisms of manipulators.

TRIBOLOGICAL CRITERIA

The primary function of the machine following, among others, are and tribological appearances - friction and wear between the elements of kinematic pairs - joints, of kinematic chain of machine. The consequences of tribological appearances are loss of effective power of driving mechanisms and reducing the lifetime of elements of kinematic pairs.

Generally, friction is defined as resistance to relative motion between two surfaces in contact. During the manipulation task of machine comes to explicit relative motion of elements of manipulator's kinematic pairs and under the loading. From these reasons, setting up tribological criteria of optimal determining the parameters of driving mechanisms manipulators based on the loss of energy due to frictional resistance in the joints of mechanisms. For determining tribological criteria of optimization, first are defined the general tribological factors and then is analyzed the impact of parameters of driving mechanisms on their size.

Tribological factors

According to the general tribological settings, the joints of manipulator's driving mechanisms make tribomechanical subsystems, which parameters of structure transform the function parameters in the effective parameters of driving mechanisms with the occurrence of energy loss and materials expressed by tribological parameters.

Parameters of joint function of machine's manipulator are: range δ_{ij} and relative motion velocity ω_i and loading F_{ri}, M_{ri} elements of the joint. Range and relative motion velocity elements of joints repre-sent the kinematic values determined with manipulation task. Loading elements of joint O_i (Figure 2a,b) are determines with fictive interruption of manipulator's kinematic chain in same joint, and reduction at the center of the joint of all external resistance W, M_w and internal (inertial and gravitational) loadings F_{ju}, M_{ju} separated part of the chain j>i, including force F_{ci} and moment M_{pi} of drive ci (hydro cylinder) of joint [4]:

$$\vec{F}_{ri} = \vec{F}_{ci} + \vec{W} + \sum_{j=i}^{n} \vec{F}_{ju} \tag{1}$$

$$\vec{M}_{ri} = \vec{M}_{pi} + \vec{M}_{w} + \left[\vec{r}_{w} - \vec{r}_{i}, \vec{W}\right] + \sum_{j}^{n} M_{ju} + \sum_{j=i}^{n} \left[\vec{r}_{tj} - \vec{r}_{i}, \vec{F}_{ju}\right] \tag{2}$$

Loading elements of the joint can be decomposing (Figure 2v) on the components collinear and normal to the axis e_i of the joint:

$$\vec{F}_{ri} = \vec{F}_{ni} + \vec{F}_{zi} \tag{3}$$

$$\vec{M}_{ri} = \vec{M}_{ni} \tag{4}$$

During the manipulative task drive moment of mechanism M_{pi} (Figure 2c) overcoming the moment's components of loading collinear with the axis of the joint e_i, so that, according to the equation 2, the resulting moment for axis of the joint is: $M_{zi}=0$.

Other components the joint loading F_{ni}, F_{zi}, M_{ni} strained the construction of the joint, but particular cause friction between its of elements.

For the plane configuration of manipulator's driving mechanism, according to equation 3, only the normal force F_{ni} that burdens the joint, depends among other loading and from reduced force F_{ci} of drive (hydro cylinder), apropos of parameters of driving mechanism.

On the other loadings of the joint F_{zi}, M_{ni}, parameters of driving mechanism have no effect because the reduced force of drive operates in a plane of manipulator normally on the axis of the joint. Therefore, from loading of the joint, as one of tribological criteria factors of optimization of manipulator's driving mechanisms, taking only the normal force F_{ni}. This force is besides being burdening the construction of the joint causes and friction between its relatively movable elements.

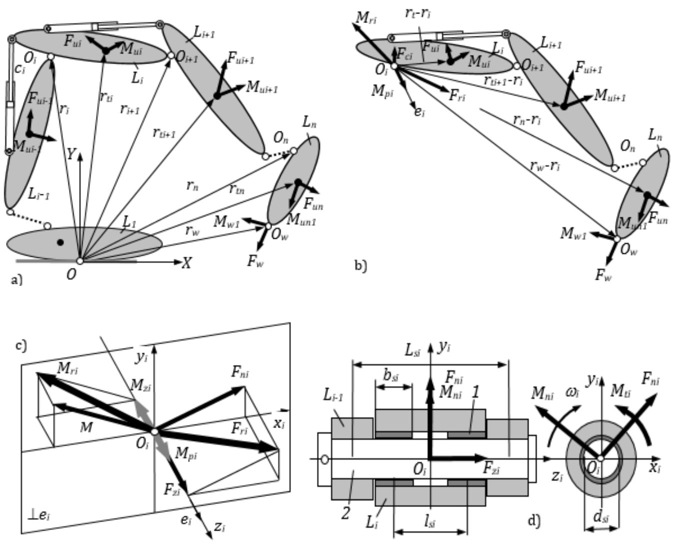

Figure 2. Tribological criteria of driving mechanisms optimization - Loading analysis of the joint kinematic pair of mechanism

ANALYSIS

How much are the impact parameters of driving mechanisms on the joints of loading show the following analysis. Observing are two comparative mechanisms, one with smaller transformational (smaller diameter piston D_1 and connecting rod d_1 of hydro cylinder c_1) (Figure 3a) and larger transmission parameter (larger connection length r_1) and second with larger transformational ($D_2>D_1$,$d_2>d_1$, of hydro cylinder c_2) but smaller transmission ($r_2<r_1$) parameters (Figure 3b).

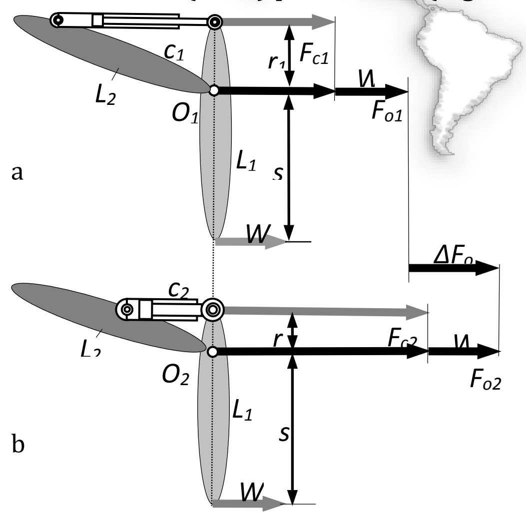

Figure 3. Comparative analysis of loading of the joint mechanism

Mechanisms have the same overall transfer function of drive moment and executive segments with the same kinematic lengths s on which ends act the same vector of external loading W. Because the simpler analysis are considered the position of mechanisms when the directions of activities forces in the hydro cylinders parallel to the directions of the resistance movement forces. With the introduced assumptions, forces in the hydro cylinders of mechanisms have value (Figure 3):

$$F_{c1} = \frac{W \cdot s}{r_1} \tag{5}$$

$$F_{c2} = \frac{W \cdot s}{r_2} \tag{6}$$

Forces F_{o1} and F_{o2} in the joints kinematic pairs of mechanisms are:

$$F_{o1} = F_{c1} + W = W(\frac{s}{r_1} + 1) \tag{7}$$

$$F_{o2} = F_{c2} + W = W(\frac{s}{r_2} + 1) \tag{8}$$

The difference of forces ΔFo in the joints exists and is:

$$\Delta F_o = F_{o2} - F_{o1} = W \cdot s(\frac{1}{r_2} - \frac{1}{r_1}) \ \forall \ r_2 < r_1 \Rightarrow \Delta F_o > 0 \tag{9}$$

Obtained results of performed analysis shows that variant solutions of driving mechanisms with smaller transformational, and larger transmission parameters, have smaller loading of the joint elements, and vice versa.

Structure parameters of the joint define: shape, macro and micro geometry and material elements of joint, as an agency and method for lubrication of the joint. Elements of rotating joins, fifth class of manipulator's driving mechanisms, are performed in the form of one pair of sliding sleeve 1 (Figure 2g) embedded in the hub of a relatively movable segment L_i and bolt 2 linked to a relatively fixed segment L_{i-1} of kinematic pair.

Macro-geometry was determined basic dimensions of the joint: diameter of bolt (shaft) d_{si}, width of sliding sleeve b_{si}, diameter of hubs D_{si}, range of sleeve l_{si} and range of hubs L_{si}.

Micro-geometry refers to the quality of surfaces and type of overlap elements of the joint. As an indicator of parameters impact of driving mechanisms on the structural parameters of the joint is determined based on loading and mechanical characteristics the elements of joint, shaft diameter (bolt) of joint:

$$d_{si} = \max \begin{cases} (F_{nmi} / 2 \cdot e_{si} \cdot p_{sm})^{1/2} \\ (2 \cdot F_{nmi} / \pi \cdot \tau_{sm})^{1/2} \\ [8 \cdot F_{nmi}(L_{si} - l_{si}) / \pi \cdot \sigma_{sm}]^{1/3} \end{cases} \tag{10}$$

where: F_{nmi} - maximum value of force which burdens the elements of joint, acting normal to the axis of joint, e_{si} - ratio of width sliding sleeve l_{si} and shaft diameter d_{si} of joint (Figure 2g), p_{sm},τ_{sm},σ_{sm} - allowed stresses of the surface pressure, shearing and bending the elements of joint.

Equation 10 shows that for the same materials of elements of joints, variant solutions of driving mechanisms with smaller transformational and larger transmission parameters have, due to smaller loading, smaller sizes elements of joints, and vice versa.

Tribological parameters of joint are related to friction and wear between elements of joint. The consequence of friction between elements of joint of driving mechanisms is the loss of energy during its transfer with occurrence of the thermal loading of joint. Due to wear caused the loss of materials and changes microgeometry elements of the joint.

According to the function parameters and structure of the joint, tribological parameters are:

a) Moment Mti of friction between elements of joint:

$$M_{ti} = -\mathrm{sign}(\omega_i)\frac{d_{si}}{2}\mu_{tz}\cdot F_{ni} \quad (11)$$

b) Power Nti lost due to frictional resistance between elements of joint:

$$N_{ti} = M_{ti}\cdot\omega_i \quad (12)$$

where: ω_i – angular velocity of executive segment of mechanism, μ_{tz} - coefficient of friction between the sliding elements of the joint.

The last two equations show that, for the same material of elements of the joints p_{sm} and same lubrication conditions μ_{tz}, variant solutions of driving mechanisms with smaller transformational but larger transmission parameters have less power losses due to the occurrence of frictional resistance between of elements of the joints and vice versa.

CRITERIA OF OPTIMIZATION

Based on the above performed analysis sets up tribological criteria of the optimal determining parameters of machine manipulator's driving mechanisms with the aim that power loss due to frictional resistance between the mechanism's elements of joint would be minimal:

$$K_2 = \min\left(\sum_i^n N_{ti}\right) \quad (13)$$

where: n - number of manipulator's driving mechanisms.

As a relative indicator kr2 of tribological criteria of optimization takes are mechanical efficiency η_m of driving mechanisms for the certain position of the manipulator:

$$k_{r2} = \eta_m = \prod_i^n \frac{N_i}{N_i + N_{ti}} = \prod_i^n \frac{M_{pi}}{M_{pi} + M_{ti}} \quad (14)$$

where: N_i, M_{pi} – power, apropos driving moment, of mechanism without friction in the joints [5].

CONCLUSIONS

Defined tribological criteria shows that the syntheses of driving mechanisms crank manipulators of mobile machines should aim choosing smaller transformation and larger transmission parameters of mechanisms. Because with smaller forces of hydro cylinders and larger connection lengths - which hydro cylinder binds to segments of the mechanism, it provides less loading of joint mechanism for the same external loading. Lower loading of joints mechanisms cause less frictional resistance and wear between the elements of joints which increases the total mechanical efficiency and lifetime of the mechanism.

Acknowledgment

This paper is financially supported by the Ministry of Education and Science of Republic of Serbia, Project No. 35049. This support is gratefully acknowledged.

Note

This paper is based on the paper presented at The VIth International Conference Industrial Engineering and Environmental Protection 2016 – IIZS 2016, organized by University of Novi Sad, Technical Faculty "Mihajlo Pupin" Zrenjanin, in Zrenjanin, SERBIA, October 13–14, 2016.

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10th years ANNIVERSARY
ACTA Technica CORVINIENSIS BULLETIN OF ENGINEERING
ISSN:2067-3809