- SUMMARY OF THE PHD THESYS -

RESEARCH REGARDING IMPROVEMENT OF DESIGN AND FUNCTIONAL PARAMETERS FOR PLANETARY SPEED REDUCERS USED IN INDUSTRIAL ROBOTS

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The subject of the research paper represents one of the most important aspects of the industrial robots as well as industrial machinery using closed-loop mechanical transmissions. The presence of the planetary speed reducers in the structure of the entire transmission represents an essential aspect, and the torsional stiffness, backlash as well as inertial masses represent vital parameters in the development of a high quality level of the final products.

The first chapter of the paper shows a study of the actual achievements concerning research, construction and performance level of the industrial robots where the main focus represents the use of the planetary speed reducers in the structure of the kinematic chains. The areas of application , advantages and disadvantages as well as principles of operation of the planetary speed reducers are also presented. A comparative approach concerning the performances and construction of the planetary speed reducers is shown for 2K-H as well as for 3K planetary speed reducers where the main quality factors are highlighted: transmission ratio, efficiency, number of stages, torsional stiffness and mass.

This chapter also shows the actual theoretical and experimental research for different types of planetary speed reducers, directed towards improvement of the efficiency, transmission radio as well as minimization of the flank play. Moreover, the research methods concerning other interacting factors that contribute to the improvement of the reliability, efficiency, inertia are shown. The first chapter ends with critical observations meant to define the research directions and establish the main goal of the research thesis concerning improvement of constructive and functional parameters of the planetary speed reducers (backlash, torsional stiffness, efficiency, vibration level as well as thermal regime) by:

1. Theoretical and experimental research concerning peripheral speeds, dynamic behaviour, torsional stiffness and angular play of the planetary speed reducers as well as establishing optimization strategies of the parameters subject to this research;
2. Experimental research concerning thermal regime as well as noise and vibration levels during operation of the planetary speed reducers with optimized parameters.

The second chapter of this research paper, theoretical research concerning peripheral speeds of the planetary speed reducers used for the kinematic couplings of industrial robots are presented. The purpose of the optimization concerning peripheral speeds represents the achievement of low peripheral speeds for high number of revolutions of the input shaft, which leads to a reduction of the noise and vibration during functioning of the planetary speed reducer as well as improving the hydraulic efficiency, part of the planetary speed reducer’s overall efficiency. At the same time, an improvement concerning the thermal regime of the planetary speed reducer takes place, since the low peripheral speeds of the gears and planet carrier lead to minimization of the power losses by friction. A method of theoretical research concerning the peripheral speeds of the rotating elements was developed applied for a number of four types of planetary speed reducers, starting from their kinematic diagram and applying

the summation method (Swamp's rule) in order to determine the transmission ratios for all elements that perform a rotational movement.

The third chapter of the paper, a method of determination of the gyration torque reduced to the motor shaft, applied to the four types of planetary speed reducers previously researched as well as the determination of the response times. A series of shapes for the planet carrier are shown in a comparative approach, meant to optimize the dynamic behaviour of the planetary speed reducers from the standpoint of response times by minimizing the planet carrier's own gyration torque. The transient regimes obtained are presented in a graphical form, followed by the formulation of conclusions and recommendations concerning improvement of the dynamic behaviour for planetary speed reducers used for industrial robots.

The fourth and fifth chapters of the paper show theoretical contributions concerning the improvement of the torsional stiffness as well as minimization of the flank play for planetary speed reducers used for industrial robots. In order to determine the contributing factors for the torsional stiffness, a mathematical model is done from the kinematic diagram of the planetary speed reducer, and then, the gearing loads are represented. A special attention is given to the type of rolling bearings used by the rotational elements of the planetary speed reducer as well as the mode of support for the planet gears, influencing the torsional stiffness.

The result of this research shows that deflections taking place at the bearings as well as their stiffness are influenced by the contact between rolling bodies. From this point of view, it is recommended that roller bearings to be used in the construction of the planetary speed reducers as a result of their higher stiffness compared to ball bearings. Increasing the torsional stiffness of the planetary speed reducer can be done using a „proper" dimensioning of the planetary speed reducer's components subjected to the same loads as their bearings because their elastic deformations are summed to the ones corresponding to the bearings and therefore have a direct influence in attaining the torsional stiffness.

The sixth chapter of this paper presents the experimental testing stand as well as measurement procedures used for data aquisition. The experimental testing rig was designed to initiate the experimental research concerning the main parameters of the planetary speed reducer that was subjected to a series of constructive modifications concerning the flank play of the gears that form the second stage, the pretensioning load of the bearings being also modified in order to increase the torsional stiffness at the same time, modifying the lubrication of the planetary speed reducer. The beginning of the sixth chapter also shows the experimental plan being used.

The seventh chapter of the paper show the experimental results concerning improvement of the constructive and functional parameters of planetary speed reducers used for industrial robots. It was presented:

1. Results concerning influence of rotational speed variation at the input shaft of the planetary speed reducer over the positioning transient regime as well as variation speed of the vibration amplitudes and noise level for idle operation. By analysing these results, some conclusions and recommendations are made for designers and manufacturers of planetary speed reducers for industrial robots.
2. Results concerning the influence of rotational speed variation at the input shaft of the planetary speed reducer over the positioning transient regime as well as variation

speed of the vibration amplitudes and noise level for load operation (0,041; 0,083; 0,125; 0,167; 0,229; 0,292 [daN·m]). From the comparative analysis, conclusions and recommendations are presented regarding the interpretations of the response times in the context of the use of PID parameters corresponding the variable frequency drive (VFD) taking into account the variation of the resistant torque at the planetary speed reducer's output shaft. The same comparative approaches are also done for the case of monitoring the noise and vibration levels corresponding to the variation of the rotational speed and resistant torque.

3. Results of the experimental research concerning influence of rotational speed variation at the input shaft as well as load applied to the output shaft over the temperature distribution for the planetary speed reducer. The conclusions for this experimental research show the correlation between the peripheral speeds and temperature distributions as well as the smaller influences of bearings preload and flank plays corresponding to the gears of the second stage belonging to the planetary speed reducer.
4. Results of the experimental research concerning the influence of the resistant torque applied to the planetary speed reducer's output shaft over the torsional stiffness. The conclusions from this paragraph show the supremacy of these solutions of achieving a low backlash related to the variation of resistant torque at horizontal displacements of the moving elements. For vertical displacements of the moving elements, some additional recommendations are made concerning the improvement of the torsional stiffness for planetary speed reducers.

The eighth chapter of the research paper presents the general conclusions arising from the entire thesis are synthetised, also the original contributions concerning theoretical and experimental research methodology of improving the constructive and functional parameters for planetary speed reducers used for industrial robots are highlighted.