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A Review on Design of a Gear Train for 500Nm Electric Rotary Actuator

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Abstract- This paper includes the basic information about the electric rotary actuator for valve operation application. The construction and operation scheme of electric rotary actuator has been given in this paper. A literature review on different papers is presented that consist of design of gears and gear train, concepts and methods of analyzing the design performance are also put together in the paper. An effort is made in this paper to find out the best procedure and tools for designing and developingan electric rotary actuator.

Keywords: *electric rotary actuator, gear train optimization, analysis of gear*

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I. INTRODUCTION

An electric actuator is basically a motor with a mechanism allowing the remote control of a device (valve or damper).in a more descriptive manner it could be given as ‘an electric actuator is a gear drive driven by an electric motor , enables the movement of the valve. A hand wheel is often supplied to drive the actuator manually. The actuator is equipped with a travel limit switches that can stop the valve in open or close position. Most of the time , a torque limit switch is also provided to complete the control system of the actuator. The actuator technology is determined by the type of operation of device to be driven.

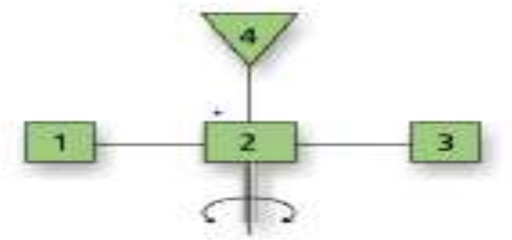

Figure 1. Schematic arrangement of the actuator

Where:

1. Motor
2. Gear unit
3. Switching and signaling devices
4. Hand wheel

The rotary movement of standard motor is geared down by means of spur and worm gear combination for reduced speed and increased torque. Suitable steps in the gear ratios enable selection of driving speed s with wide ranges. Motor drives the output shaft through spur reduction gear, and worm and worm wheel, thus reducing speed andmultiplying torque. In specific models torque further gets multiplied by reducing speed through a set of planetary gears. The actuator output shaft is then suitably coupled to the valve spindle.

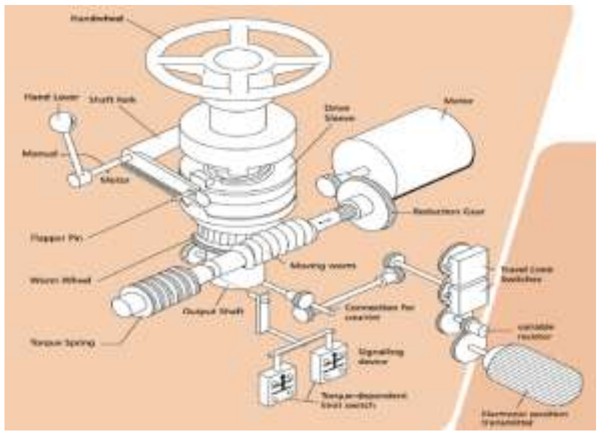

Fig.2.General arrangement of actuator components

II. LITERATURE REVIEW

1) J. Stryczek et. al. has presented the work of designing the polyoxymethelene cycloidal gear (POM) manufacturing process with the use of specially designed injection mould. The design work was initialized with strength analysis of the pumps gear system. The experimental model of the gerotor pump with the POM gears and test stand has been also presented in his work. A step by step procedure has been provided for the design of the pump and the gear system. The load on the gear system resulting from the torque M and the pressure of the working fluid are the causes of the deformation and stress in the system. Which were concerned

and optimized in the study. A stress condition was determined for the system viz.

σ_{red}<=σ_{rmax} =Re=60mpa.

The deformation condition are evaluated and tested. Results of FEM analysis are used to specify the determinants for POM cycloidal gears such as low tooth depth coefficients ʎ also the transmitting torque. As a result of the conducted design, production and experimental work, a general methodology of designing plastic fluid power elements were formulated. It includes the following stages: - development of the elements' concept, including the definition of their shape and size; - strength analyses of the models of the elements using the FEM and the prognosis of their load-carrying capacity depending on the stress and deformations; - design of the element or system; - technological, including the design and manufacture of the injection mould as well as the design and manufacture of the gear system; - experimental research, when the verification of the gear system's operation in the pump is performed and the real technical parameters of the pump are determined.

2) In this paper, Ram Sudarsan Devendran and Andrea Vacca have presented an innovative procedure for determining the optimal design of an external spur gear pump for a particular emission reduction application in automobiles. The proposed research proves to be an advance in gear machine design by using a multi-objective based genetic algorithm, to determine the optimal design of the gears and the casing by maximizing the volumetric efficiency, minimizing pressure overshoots, localized cavitation and noise emissions. The research uses HYGESim (Hydraulic gear machines Simulator) simulation tool, which is being developed by the authors' research group, for calculating the important performance features of the machine.

In this study, the determination of the optimal design of the GM (gear machine) is formulated as an optimization problem; thus defining proper design variables which need to be optimized based on the objective functions representative of the design requirements described. Thus, the proposed research is representative of a step ahead of the past mentioned works which only aimed at studying/improving only one particular aspect of the GMs operation neglecting the complex interactions among the different goals.

The features of operation of an external gear machine are strongly affected by factors (such as the radial and lateral leakages, the radial micro-motion of the gears, the features of the meshing process) which are concerned during the study. The tool used in this work for performing the different calculation is HYGESim: HYdraulic GEar machines Simulator (HYGESim developed by the authors' research group) which permits to have high accuracy of simulation. Past work made by the authors' team demonstrated the importance of such aspects, showing also validation on the basis of experimental results.

3) W. Kollek and U. Radziwanowska have presented the results of the static mechanical analysis of a gear micropump body. Numerical simulations using finite element method (FEM) were conducted using Ansys Multiphysics software. After analysis of stress and displacement distribution in the pump body, a mass optimization of construction was provided. In the optimized body, maximal value of stress reached 134 MPa. Safety factor was equal to 2.9. The highest value of displacement in the optimized body was about 0.02 mm. Maximal values of stress and displacement provide appropriate work of the micropump. Strength and stiffness criteria in the optimized pump body were achieved. For the construction of the pump body before and after optimization, energetic efficiency ratios (kef) were calculated. Optimized micropump body has more than 30% increases in kef ratio to the pump with the primary body.

As the result of the gear micro-pump body optimization, the dimensions and mass of the structure were significantly reduced. The body mass before optimization was about 150 g, while after the reduction of the overall dimensions, it was only about 63 g. Body mass of the original pump body (pump body I), the optimized body (pump body II) and mass of the entire pump with pump body I and pump body II are compared. For both pump bodies, energy efficiency ratio (kef) was designated in the article.

4) BingzhaoGao and Qiong Liang et.al. has provided a mechanism which includes the use of 2 speed transmission with the drive motor which improves dynamic and economic performance of the electric passenger vehicle. A novel 2-speed I-AMT (Inverse Automated Manual Transmission) and the dry clutch is used at the rear of the transmission so that the traction interruption of traditional AMT can be cancelled. After the gear ratios are optimized using Dynamic Programming, gear shift control is addressed, and smooth shift process without torque hole is achieved through feed- forward and feed-back control of the clutch and the motor. Finally the proposed electric vehicle (EV) is compared with an EV with fixed-ratio gear box, and it is shown that the 2-speed AMT with a rear-mounted dry clutch has much better performance in terms of acceleration time, maximum speed and energy economy. The effect of clutch friction loss during shifting on the energy efficiency of the whole driving range is analyzed as well.

5) B.Venkatesha and S.V.PrabhakarVattikuti et.al. has focused on the investigation of combined effect of gear ratio, helix angle, face width and normal module on bending and compressive stress of high speed helical gear. Bending

and compressive stress were calculated using design equations. The results were checked with the use of MATLAB software. The results were calculated with steel alloys. Such study is very useful in recent competitive global market.

6) Wan-Sung Lin and Yi-Pei Shih et.al. presented a work on the design of a new two-stage cycloidal speed reducer with tooth modifications. The topological structure of cycloidal drives is discussed and analyzed with the aid of graphs. New cycloidal gear reducers are enumerated through the topological analysis and a new two-stage cycloidal gear reducer with simpler structure is proposed in this paper. The design of the proposed cycloidal gear reducer is also performed, including profile generation and modifications. Subsequently, kinematic errors are analyzed by using the tooth contact analysis, and the results caused by different combinations of the gear profile modifications are presented quantitatively. Based on the analysis, a mock-up of the cycloidal gear drive is constructed to validate the feasibility of the new mechanism.

7) NenadMarjanovic et.al.has presented the characteristics and problems of optimization of gear trains with spur gears. They provided a description for selection of the optimal concept, based on selection matrix, selection of optimal materials, optimal gear ratio and optimal positions of shaft axes. Further presents the definition of mathematical model, with an example of optimization of gear trains with spur gears, using original software. Using an approach like this for the optimization of gear trains with spur gears gives results that can be applied in practice.

8) V. Savsani et.al. has reviewed the problem of minimum weight design of simple and multi-stage spur gear trains, since, many high-performance power transmission applications (e.g., automotive, aerospace, machine tools, etc.) require low weight. They have presented two advanced optimization algorithms known as particle swarm optimization (PSO) and simulated annealing (SA) to find the optimal combination of design parameters for minimum weight of a spur gear train. The results of the proposed algorithms are compared with the previously published results. It is observed that the proposed algorithms offer better gear design solutions.

9) Sa'idGolabi et.al. in his study, proposed the general form of objective function and design constraints for the volume/ weight of a gearbox. The objective function and constraints can be used for any number of stages for gearbox ratio but in this paper one, two and three-stage gear trains have been considered and by using a Matlab program, the volume/weight of the gearbox is minimized. Finally, by choosing different values for the input power, gear ratio and hardness of gears the practical graphs from the results of the optimization are presented. From the graphs, all the necessary parameters of the gearbox such as number of stages, modules, face width of gears, and shaft diameter can be derived. The results are compared with those reported in the previous works and an example is presented to show how the practical graphs can be used.

10) Ketan Tamboli et.al.has written a paper which presents helical gear pair of a heavy duty gear reducer is considered for the objective of minimum volume, since the most power transmission systems require low weight energy efficient and cost effective system elements. The various factors for sizing and strength of gears are computed for gear geometry parameters using DIN standard. The formulation of the constrained non-linear multi-variable optimization problem with derived objective function and constraints is presented. The solution is attempted using Particle Swarm Optimization (PSO). The results achieved were satisfactory and helps designer to employ for minimum material and cost by fulfilling the strength and performance requirements.

11)Alain Bernard has presented a paper which aims to present the new method developed to generate optimized spiral bevel gear surfaces. By the use of complex nonlinear finite element model, the geometrical gear meshing positions under operational loads were precisely computed first. These meshing positions are then used as inputs of a calculation process that seeks to define the best tooth surface topography. This paper describes the new process implemented to design the tooth shape

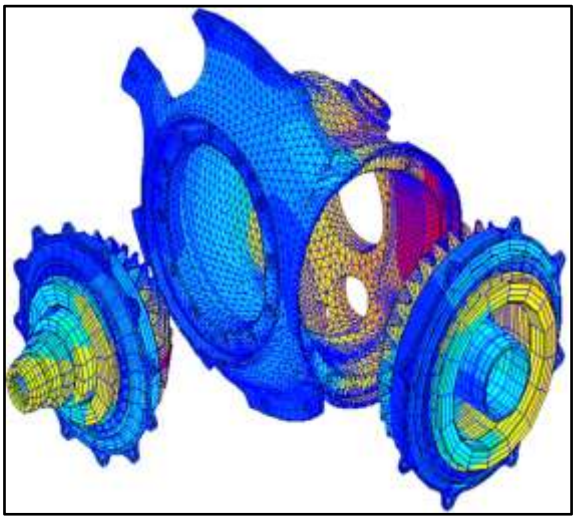

Fig3.Example of complex FEM models

12) Marco Barbieri et.al.has worked on the solving the contact problem for generic helical gear pairs (either external or internal). Gear profiles are obtained by means of numerical simulation of the cutting process and an accurate description is provided in terms of NURBS curves or surfaces. A new method for finding the enveloping profiles for a generic tool (e.g. from a measured topography) is proposed. The method allows to automatically performing a Loaded Tooth Contact Analysis (LTCA) starting from the

design data of a gear pair. Information about the Static Transmission Error (STE) and mesh stiffness is provided. The whole procedure has been implemented in software called helical pair.

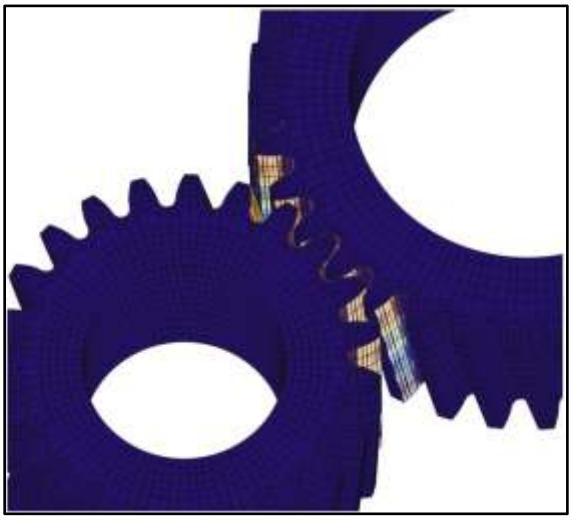

Fig4. 3D finite element model prior to refinement

III. CONCLUSIONS

Study of such impressive work lead us to form a methodology to develop a gear train for any kind of machines, that may giving output in the form of pressure like in micro-pumps[3], gerotor pump or the output may be in the form of torque like in electric motor vehicles[4] and electric rotary actuator etc.. The methodology for developing the new 500Nm rotary actuator can be

1) Selecting the motor regarding the output torque and speed
2) Selecting the prior gear ratio
3) Selecting the prior gear train
4) Design the gears in terms of load bearing capacity and mechanical efficiency. Perform the FEM analysis for the confirmation of theoretical design.
5) Optimization of gears and the gear box casing according to the values obtained in the analysis.

A design methodology for simultaneous optimization of gears and grooves for gear machines [2] is also presented in the given work. Although the procedures was described for a particular design of gear machine which are used for low pressure applications. The design can be extended to different machines [2]. Another conclusion is that, FEM analysis can be done and could be used for electric rotary actuator [3]. This study has led to many benefits in gear manufacturing such as reduction in redundancies, constant containment related to adjustment and interchangeability provision [4]. Bending and compressive stress analysis is performed for the evolution of design [4].

Adaptive grid size finite element analysis method is used for the design evaluation of helical gear is recommended in the paper of B. Venkatesh [6].

Method of LTCA is presented in the paper [7] which is also useful in formulating the bending stress in steel alloy. This can be also used in designing the gears for electric rotary actuator's gears.

Method of swarn optimization and simulated annealing algorithm is suggested by the author for optimal weight design [8] which could be useful in weight optimization in new product design and development. Bevel gear topography provides very helpful aid for finalizing the gear mechanism.

Such a study is definitely going to put forward a helping hand in developing a new product containing a gear mechanism.

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