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Design and Development of 450Nm Rising Spindle Actuator: A Case Study

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Abstract— In the recent world of industrialization, it becomes very important to adapt to the changing trends and the market demands. In order to stay in the competition, there is a need to bring about some changes in your product's conventional design and make it more reliable. In this paper, an effort is made to take the design to the next level. This paper presents the use of concept selection matrix and basic procedure in the process of designing the 450nm rising spindle electric rotary actuator.

Keywords*-design,rising spindle actuator; concept selection matrix.*

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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.

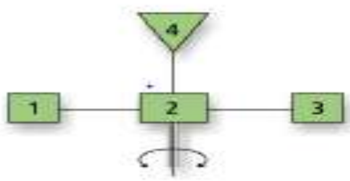

Figure.01. Schematic arrangement of the actuator

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 and multiplying 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. The full load efficiency of the actuator of the present design is 56%. That means, for an actuator designing a torque of 356nm willl provide a torque of 200nm. The output speed of the recent actuator is 19rpm but our aim is to get an op speed about 50 rpm. The purpose of the new design is to provide good speed at good torque. This study is to check whether the theoretical values of new design actually give the same torque values and speed values for. Fig. 1 general arrangement of conventional SD3000 actuator components

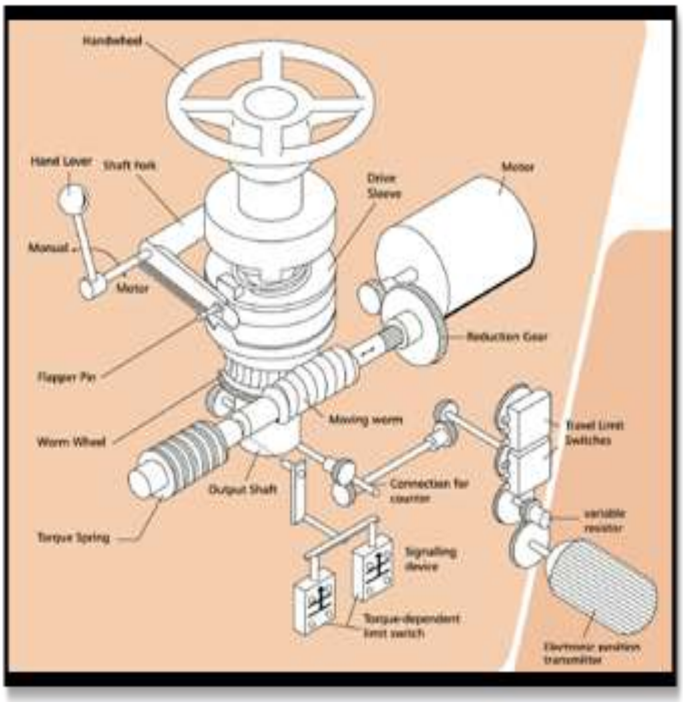

Fig.02.General arrangement of components of the SD3000 actuator

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II. LITERATURE REVIEW

Nenad Marjanovic et.al.[1]has presented the characteristics and problems of optimization of gear trains with spur gears. It provides 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. The design of minimum weight gear trains using particle swarm optimization and simulated annealing algorithms is performed. Optimization of gear trains with spur gears uses formulation of mathematical model. Optimal concept of gear train with spur gears can be selected by selection matrix. Author has formulated the selection matrix which is made by combination of various gear pairs in certain stages. Selection matrix can be used for the selection of acceptable concepts of gear trains with spur gear. The author has presented the method of concept for selection of optimal materials, gear ratio for gear trains, optimum position of shaft axes. The problem of optimization of gear train is performed with the help of software tool called GTO.

Many researchers have focused on gear analysis, the major concerns of gear analysis deals with the analysis of gear stresses, transmission errors, dynamic loads, noise, and failure of gear tooth, which are very useful for optimal design of gear set. B.Venkatesh et.al has worked on the formation of input parameters which influence the output parameters viz. bending stress, compressive stress.[3] A method for the load and stress distributions is put forward. This method includes the tooth profile modification and crowning, manufacturing and alignment error of gears, tooth deflections, local contact deformations of the teeth. It also covers the influence of gear parameters on the load and stress distributions

Sorniotti, S. Subramanyan,[6] proposes an optimization procedure which takes into account the efficiency characteristics of the whole vehicle power train to select the optimal gear ratio The geometric design (Shuting Li)[5] of the trochoidal gear reducers is developed with the help of AutoCAD software and strength analysis is performed with the help of FEM software tool.

III. PRESENT DESIGN TORQUE AND SPEED CALCULATIONS

The conventional actuator SD3000 is designed with worm and worm shaft reduction as its main reduction mechanism. The efficiency of the gear mechanism is attested as 56%. That means, for an actuator designed for the torque of 356nm willl provide a torque of 200nm. The output speed of the recent actuator is 19rpm but it gets even low when to achieve more torque with the help of supplementary gear box. The purpose of the new design is to provide good speed at good torque. This study is to check whether the theoretical values of new design actually give the same torque values and speed values for which it is designed for when compared with conventional design.

The range of torque has been calculated for the given values of spur gear ratio at 1st reduction. In order to find out probable efficiency of the given design of actuator.

Gear ratio(spur)	1.5	1.05	0.78	0.48	1.16

The values of torque are formulated by keeping the gear ratio cosntant and changing the motor specifications available.viz.

Motor	Kw	Torque, Nm	Rpm
Motor 1	0.74	5.1	1400
Motor 2	2.2	7.4	2800
Motor 3	3.2	20.4	1430

Table.01.Motor specifications

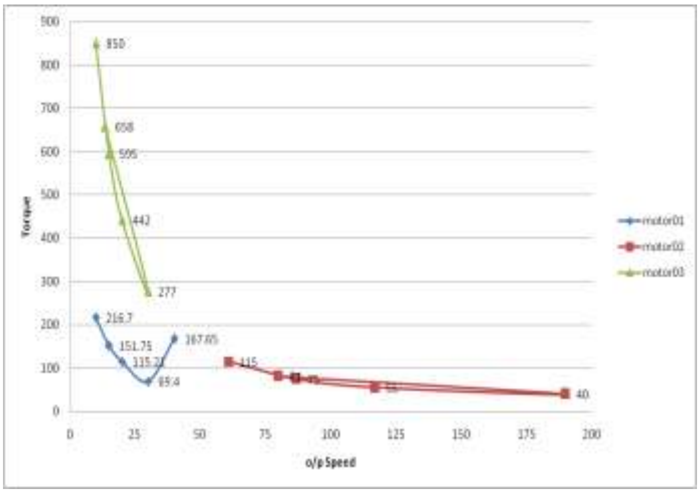

Table.03.Torque calculation per stage with variable spur gear ratio of SD3000

A. *The need for new design*

The design showed above has some drawbacks

- The main reduction in the actuator is worm and worm wheel reduction which is 1:30. But the efficiency of this gear pair always lie between the range 30-35%.

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1132 – 1137

- The overall efficiency of the actuator is 56% which is considerably low.
- To achieve a speed more than 400rpm, it is not possible to attain a torque without compensating the speed. In order attain a good rpm, the use of supplementary gear box(SG) becomes mandatory which again leads to lower speed.
- The supplementary gearbox has to be purchased distinctively but if the SG is manufactured within the body of actuator it can reduce at least one gear stage.

B. The aim of the project

1. To propose the design concept without worm reduction.
2. To make the epicyclic reduction inside the gear box body.
3. To propose the design concept that will give away more speed with 450nm than the present design.

IV. THE NEW DESIGN CONCEPT FOR ACTUATOR

In order to achieve the good o/p speed with 450 nm torque at the same time, it becomes essential to go for the motor with higher power. The need of the design is good speed so it has to be a speed oriented design. Gear trains are complex technical systems. Numerous complex equations, depending on a large number design variables, are used for their mathematical formulation and many influence factors have to be taken into consideration as well.

Nenand Marjanovic et.al described the design of minimum weight gear trains using particle swarm optimization and simulated annealing algorithms. The author has presented the characteristics and problem of optimization of gear trains with spur gear. It provides a description for selection of the optimal concept, based on selection matrix selection of optimal materials, optimal gear ratio and optimal position of shaft axes.

Optimal concept of gear train with spur gears can be selected by selection matrix. Selection matrix is made by combination of various gear pairs in certain stages. Those combinations providing gear trains that cannot function or gear trains that will surely be worse by all selection criteria are eliminated at the beginning. The designation of gear train concept provides the information about: number of stages, type of gear pair ("S"— spur gear, "B"— bevel gear or "W"— worm gear) in each stage) direction of rotation ("+", "–" or "+/–") as well as the position of intermediate shafts. The concept selected out of the selection matrix is given below.

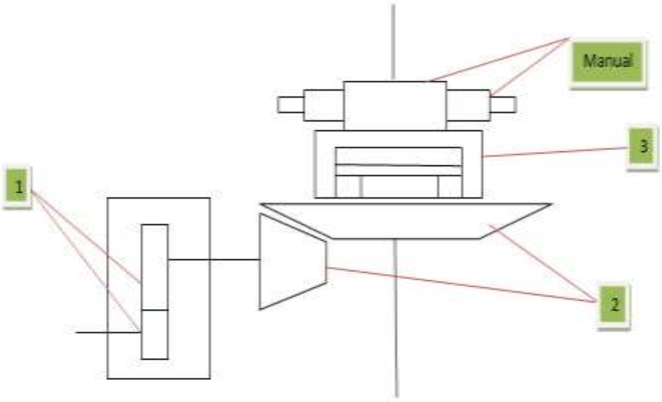

Fig.03. the new concept for the 450nm actuator

Fig.03. shows the design concept selected with the aid of concept selection matrix. Selection matrix can be summarized by providing the input apart from ordinal number, name, sketch and designation of the gear train, the following can be added to the table:

Positions of shaft axes = intersecting

Number of stages= 3
Gear ratio (u) that to be achieved=23
Approximate efficiency (η) =65% to 70%
Direction of rotation= both (+,-)

In the above figure.02.The spur reduction is denoted by '1', bevel reduction is denoted by '2', epicyclic is denoted as '3' and the 'manual' is for worm and worm wheel reduction which is provided for manual operation during power failure and also prevents the motion from transmitting in direction from output to the motor i.e. the self-locking arrangement.

A. Selection of module

In the design of a spur gear drive, the following data is usually given:

I. The power transmitted.
II. The speed of the driving gear.
III. The speed of the driven gear.
IV. Centre distance.

Since, the centre distance is given as Cd=65-70mm , the best possible diameter for the pinion and gear is taken as

$$D_p = 45\text{mm and } D_g = 85\text{mm}$$

Then the equivalent number of teeth can be found out with the help of equation,

$$T_p = 2Aw/(G[\sqrt{1+\left(\frac{1}{G}\right)\left(\frac{1}{G}+2\right)}]) \qquad (1)$$

Where,

T_P = number of teeth on the pinion

A_w=fraction by which the standard addendum for the wheel should be multiplied,

G=gear ratio or velocity ratio, $T_G/T_P=D_G/D_P=84/45=1:1.88$
=pressure angle or angle of obliquity
On the basis of equation
Module, $m=T_P/D_P$
The graph has been plotted by considering the standard values of module multiplied to the equivalent number of teeth viz. 17. and it was seen that the module, m=2.5 reaches the closest to the value of pinion diameter which is 45mm .
Hence, the module selected is 2.5mm.

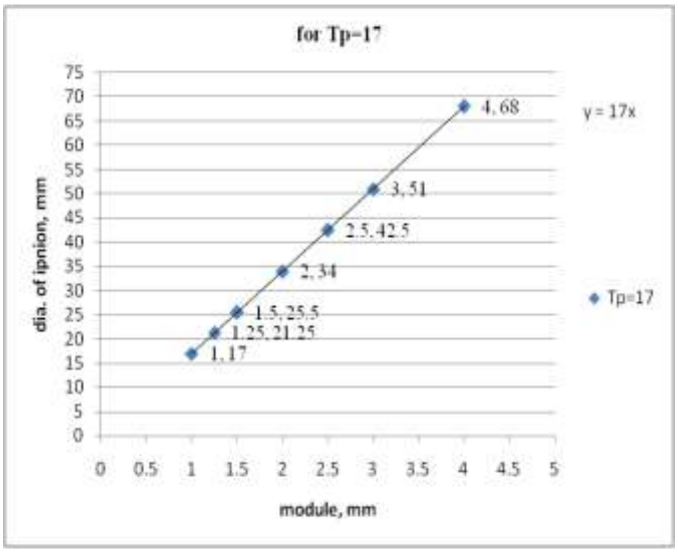

Fig.03.diameter of pinion vs. module

B. Selection of optimal gear ratio for each stage

In optimization of multi-stage gear trains it is important to select the number of stages and to properly distribute gear ratio to individual stages. Finding out the gear ratio require collective use of material properties for gear. the gear material can be varied with the application. Since, the medium carbon steel is the most suitable material for gears if the machinability is considered and perform satisfactorily for low precision gears. The use cast steel becomes mandatory when the gears are integrated part of the machine body. For spur reduction few grades of en8 are used with hardness range (100, 200, 300 BHN) and cast iron at (200BHN).

The volume of spur gear pair can be found [1] with the help of Lagrange's Multipliers method.

$$V = \left(\frac{\pi b}{4}\right)[K_{ol}^{(p)}(d^{(p)})^2 + K_{\iota} \quad (2)$$

Where: d(p) and d(g) are pitch diameters, and kol (p) and kol (g) are mass reduction factors of pinion (p) and gear (g) and b is gear width. Mass reduction factor is the ratio of approximate volume of spur gear and theoretical volume of the gear, i.e. the volume of cylinder encompassing the gear.

As shown in detail in the literature [2], applying Lagrange Multipliers method gives the following equation:

$$\frac{2k_r.u_k^2 + k_r.u_r^2 - 1}{u_k^2} = \frac{k_r.u_{k+1}^2 + k_r.u_{k+1}^2 - 2}{u_{k+1}^2} \quad (3)$$

Where,
Kr= relative reduction factor= kol (p)/kol (g) = kr = 0.7
The gear ratio that was found out to be best suitable for the design is

TABLE.04.Optimum gear ratio

Stage reduction	Spur reduction	Bevel reduction	Epicyclic reduction	Total
Gear ratio	1:1.88	1:4.43	1:2.74	22.82

V. MATERIAL SELECTION

Optimal design of gears requires the consideration of the two type parameters: Material and geometrical parameters. The choice of stronger material parameters may allow the choice of finer geometrical parameters and vice versa. Very important difference among these two parameters is that the geometrical parameters are often varied independently. On the other hand, material parameters can be inherently correlated to each other and may not be varied independently. An example of which being the variation of the bending fatigue limit (Sbf) with the core hardness (HB) for some steel materials. If these parameters would be varied independently in an optimization case, it may result in infeasible solutions. Therefore, the final choice of material may not be possible within available data base. If gear material and geometrical parameters are optimized simultaneously then it is common to assume empirical formulas approximating a relation between material parameters for example the bending fatigue limit (Sbf) and ultimate tensile strength (Rm) as a function of hardness. If the choice of material is limited to a list of pre-defined candidates, then two difficulties can be appeared. First, a discrete optimization process should be followed against material parameters. Second, properties of different alternatives materials may not indicate any obvious correlation in the given list. The main goal is to choose material with best characteristic among alternatives. Table 1. Shows suggested nine materials with their characteristics in a gear material selection process.

TABLE.05. Characteristics of alternative materials for gear selection

Material	Hardness: Surface (HB)	Hardness: Core (HB)	surface fatigue limit (MPa)	bending fatigue limit (MPa)	Rm (MPa)
Cast iron	200	200	300	100	380
Ductile iron	220	220	460	360	880
S.G. iron	180-300	180-300	480-620	240-440	590-950
Cast steel alloy	220-320	220-300	560-700	420-450	590-950
Through hardened alloy steel	220-320	220-300	600-740	500-580	800-1580
Surface hardened alloy steel	519-565	192-265	1160	680	1850
Carburized steel	601-692	256-337	1500	920	2300
Nitrided steel	647-738	256-337	1250	760	1250
Through hardened steel Carbon steel	160-210	160-210	450-550	420-440	560-710

TABLE.06.relation of module with auxiliary gear dimensions

Sr. no.	Particulars	20 full depth involute system for module, m	values
1	addendum	1m	2.5
2	dedendum	1.25m	3.125
3	working depth	2m	5
4	min. tooth depth	2.25m	5.625
5	tooth thickness	1.5708m	3.927
6	min. clearance	0.25m	0.625
7	fillet radius at tooth	0.4m	1

VI. DESIGN METHODOLOGY

After finding out the module, it becomes very easy to calculate the other particulars of the gear design owing to the relations given in TABLE06.

Design of spur gear and bevel gear pair is very simple. The use of design data book by 'Shigley et. al. 1996' was useful in designing the gears according to AGMA(American Gear Manufacturers Association) standards.

According to Lewis equation, the beam strength for spur gear and bevel gear pair tooth is given by

$$F_B = [S_{O.} C_{V.} b.\ Y.\ m] \quad (4)$$

Where,

S_O=Allowable contact strength, MPa
C_V=Velocity factor
b=Face width of gears, mm
Y=modified Lewis form factor
m= module, mm

Buckingham's equation

$$Fd = Ft+(21Vp(Ceb+Ft)/(21Vp+\sqrt{(Ceb+Ft)})) \quad (5)$$

Where,

Ft= tangential tooth load, N
V_p =pitch line velocity, m/s
C= deformation factor
e=error in profile, mm

VII. CONCLUSION

The process of concept selection has been presented. A general procedure of designing a new product is presented. The process and results of identification of module, gear ratio and loads acting on the gear toot has been performed. It was clear from the research that finding out the best material within the given dimensional tolerances is the collective process.

Finding the best material for your product doesn't always follow any fixed equation. it is sometimes more like going for the more available material which will also complement the cost. The best material chosen for the spur gear and bevel gear is medium carbon steel EN8 200BHN and for the teeth machined into cast body it has to be the cast iron.

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1132 – 1137

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