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Electro-Mechanical System Design for Seating Systems

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***Abstract*--The main aim of this paper is to focus on the innovative design of electro-mechanical system design for the actuation of seating system. The present day automotive market demands a luxurious and easy operation of seat with less mechanical effort. This paper brings out the efficient design of a gearbox, motor and associated linkages that collectively achieve the required actuation of seat within the stipulated time, lifting the required load, consuming less power.Here, the design details of gearbox, technical parameters of motor and linkages are presented in detail for the mentioned application. The CAD modeling of the design is done in Pro-E Wildfire 4.0 and the virtual analysis of critical parts of Gearbox is carried out in ANSYS 13.0 (workbench) and the results are discussed.**

Keywords:Gearbox, Motor, Linkages, Planetary arrangement, rotary motion, angular lift

1. INTRODUCTION

Automotive field is witnessing various new trends with respect to each and every sub-assembly. The seating system is not an exception. The ergonomic requirements of present day cars demand a luxurious seat adjustment mechanism that can be operated using less mechanical effort that is efficient with less power consumption. The provision to adjust the seat position in vertical axis is also a regulatory aspect in most of the geographical regions. According to Federal

Motor Vehicle Safety Standards (FMVSS) 202, the seat height has to be adjusted in such a way that, the top head restraint would be at least 76mm from the H-point.

1.1 Types of Seat Adjustment mechanisms

The seat adjustment both in vertical and horizontal axes is being achieved by two ways.

Conventional Linkage mechanism: This is the old and regular design that is operative in low end cars and other Off-highway vehicles to adjust the seat in required four-axis motions (Up-Down, Forward-Rearward). This mechanism consists of a pair of Forward and Backward Link members operated by a lever for causing vertical movement. A brake unit is adapted for limiting downward movement of the link members.

Power Operated mechanism: This is the advanced system that operates the seat by simply pressing a switch. It consists of various sub-assemblies like a motor, which is the power source, a Gearbox for torque multiplication and speed reduction and a linkage mechanism to convert the rotary motion of motor and gearbox into an angular motion which provides the lifting action for the seat.

1.2 Problem Statement-Need for New Design

The old and regular mechanism designs for operating seat are becoming obsolete due to the following reasons:

Twisting of Linkages and other screw mechanisms due to excessive impact load

More thickness, More weight, More cost – To meet safety demands including the above-stated problem, the backward link member of seat adjustment mechanism is reinforced by increasing the thickness thereof to withstand the afore-said excessive great load. But, such increase of thickness of the link member undesirably results in increase of weight of the seat height adjustment mechanism as well as in increase of costs involved

- No control in operation
- Poor Ergonomics

The existing power operated mechanisms are proven be effective in overcoming the above problems of conventional linkage mechanisms. But, there are some limitations in these designs which are mentioned below:

- Occupies more space
- More Costly
- Consumes more power
- Less efficient

Due to afore-said reasons, a new electro-mechanical design for seat adjustment is needed that overcomes all the limitations of the existing power operated seat adjustment designs.

2. DESIGN

2.1. Subsystems and Components

The design of electro-mechanical actuation system consists of the below sub-assemblies and components:

- A Planetary Gearbox
- A Motor
- Linkage Arms

2.2. Design Benefits

This design is different from the existing power operated mechanisms and is stated as innovative owing to the following reasons:

Format: Benefitwith this design– Explanation

Less Packaging space requirement– The design presented in this paper is with the small Outer Diameter that can be well accommodated in the existing crash rod of the seat structure. So no separated space is required

More Efficient Design – This design has the motor and gearbox arranged in linear to each other, thereby avoiding all mis-alignments in the operation. Also it is evident that the planetary arrangement is most efficient compared to all other gear arrangements

Less Costly Design – This design is less costly as the motor used is an Off-the shelf item and is available directly from the market. Also it is a DC motor that directly draws power from car battery

More & close control in operation – The present design has less friction and the load is equally distributed across all the gears making the seat adjustment operation more smoother without jerks

Safe Design – All the components of the design are assembled inside a crash tube. So whatever the crash loads and all the impact loads are taken by the crash rod and the design of actuation system is safe. Also, there is no need for an extra arrangement to safeguard the design from external loads and environmental factors

2.3. Functional Description

The following description explains the functionality of the components of this design and doesn’t explain the subsequent motions and other linkage behaviors of the seat structure.

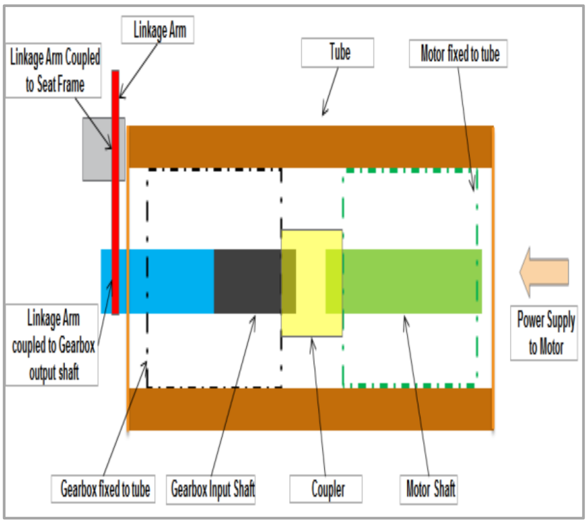


Figure 1. Functional Description

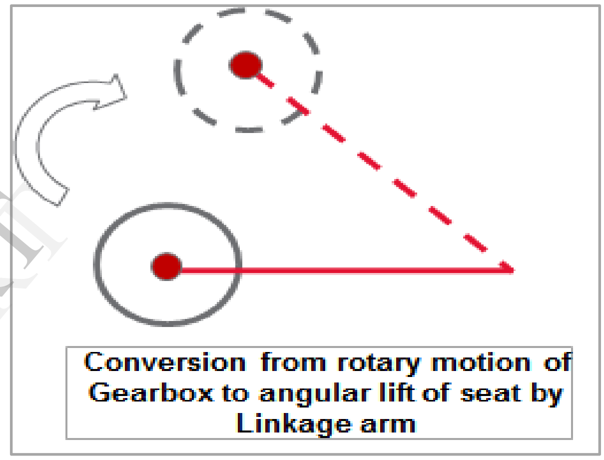


Figure 2. Motion Conversion

Referring to Figure 1 and Figure 2, the functionality is explained below in detail:

Power supply from the battery is supplied to the motor through an Electronic Control unit (ECU) which controls the bi-directional rotation of the motor. The motor shaft is coupled to the gearboxinput shaft with a coupler. The torque from the motor shaft is transferred to the gearbox shaft along the coupler. Both the motor and gearbox are fixed to the tube radially with screws on the periphery of motor and gearbox housings. A linkage arm is locked with the gearbox output shaft and is also locked with the seat frame. So the multiplied torque from the gearbox output shaft is transferred to the linkage.

As shown in Fig.2, the linkage arm is pivoted at one end and the other end is locked with the gearbox output shaft. Due to the linkage action, the seat frame along with the linkage arm is lifted in angular motion. The torque at the output shaft of the gearbox is converted into force multiplied by the linkage arm length. This is explained the formula:

Torque, T (N-mm) = Force (N) x Distance between the center of Output shaft and linkage pivot point (mm)

2.4. Actuator Specifications

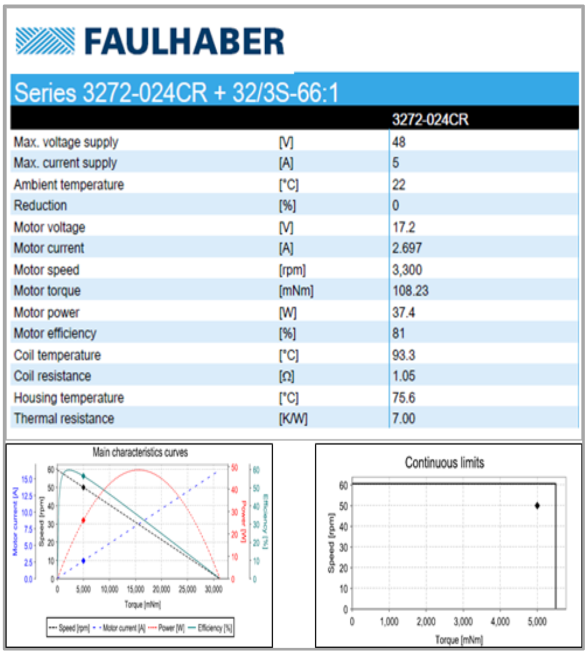
Below table provides all the technical specifications of design of electro-mechanical system

Table 1.Actuator Technical Specifications

S.N	Parameter	Specification
1	Input Voltage	12V DC
2	Input Power	60 W
3	Rated Output Torque	7 Nm
4	Peak Output Torque	11 Nm
5	Operating Temperature	-20 to +60°C
6	Overall Size	Outer Diameter to be < 40 mm
7	Weight Target	1000 grams max.
8	Ingress Protection	IP20 to IP40

2.5. Motor Selection

The motor used in the design is a Brushed D.C. Motor. Considering the output torque and output speed requirement, the motor is selected as off-the shelf item directly from a standard product catalogue. Faulhaber is a global motor manufacturer with a varied range of technical specifications. From that the suitable D.C. motor within the packaging dimensions is selected. The catalog is displayed in the below Figure 3.


FAULHABER

Series 3272-024CR + 32/3S-66:1

		3272-024CR
Max. voltage supply	[V]	48
Max. current supply	[A]	5
Ambient temperature	[°C]	22
Reduction	[%]	0
Motor voltage	[V]	17.2
Motor current	[A]	2.697
Motor speed	[rpm]	3,300
Motor torque	[mNm]	108.23
Motor power	[W]	37.4
Motor efficiency	[%]	81
Coil temperature	[°C]	93.3
Coil resistance	[Ω]	1.05
Housing temperature	[°C]	75.6
Thermal resistance	[K/W]	7.00

Figure 3. Motor Datasheet

Table 2. Motor Technical Specifications

S.N	Parameter	Specifications
1	Rated Voltage	17.2 V
2	Rated Current	2.69 A
3	Rated Torque	0.07 Nm
4	Rated Speed	3300 RPM
5	Motor Diameter	32 mm
6	Length of motor	65 mm
7	Operating Temperature	-30 to 70 ° C

2.6. Gearbox Design

Figure 4 provides the cross sectional view of Planetary Gearbox of this design.

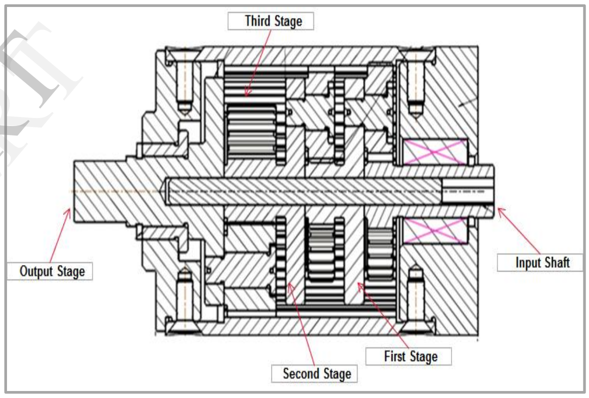


Figure 4. Planetary Gearbox – Cross Sectional View

The planetary gear arrangement is selected over the other gear arrangements owing to the below reasons:

- Large velocity reduction in less packaging space
- High efficiency & durability compared to any other mechanism
- Compact design with less noise
- Equal distribution of loads on all gears

This gearbox has got 3 stages and from the outline specifications and space availability the gear box size is finalized as Ø33 x 50 mm and selected Gear Ratio as 110

As mentioned in the earlier sections, a gearbox is required in the design to multiply the torque that is delivered from the motor and to reduce the speed.

- Planetary gear train efficiency of one pair = 94%
- Total Theoretical Efficiency for gearbox = 0.94x0.94x0.94 = 83.05%
- Considering factor of safety as 1.6, the gear box efficiency is considered as 50%

The step wise design of the gearbox is explained below:

- First step is to fix the PCD of Ring gear as Ø 28.5 mm. Selected the module as 0.5 Number of teeth are Z = PCD/module = 28.5/0.5 = 57
- Planetary Gear Reduction = 110
- Each stage reduction = cube root of 110 = 4.8
- No. of Teeth on Sun Gear is Za
- No. of Teeth on Planet Gear is Zb
- No. of teeth on Ring Gear is Zc

Gear Ratio = Zc / Za +1

= 57/Za + 1 = 4.8

Za = 15

Zb = (Zc – Za) / 2 = 57-15 / 2 = 21

Table 3. Planetary Gearbox Parameters

S.N	Gear	No. of Teeth	PCD
1	Ring Gear	57	28.5
2	Sun Gear	15	7.5
3	Planet Gear	21	10.5

Table 4. Material Used For Gears

Description	Value
Tensile Strength	1586 N/mm2
Proof Stress (0.2%)	1344 N/mm2

2.6.1. Face width calculations

Max Torque acting on Planetary Gear train gears at stage 1

- Torque at peak Load at stage 1 = 0.108 Nm
- Max speed of Planet gear at stage 1= 3300/4.8 = 687.5 rpm(Considering max speed without loss)
- PCD of Planet gear at 1st stage = 10.5 mm
- Pitch line Velocity =(ΠDN)/60 = 0.377 m/sec
- Velocity factor (Cv) = 6/(6+V) = 0.94
- Tangential Torque on tooth = (1.25*COS 20) = 1.175 N-m
- Tangential tooth Load (Wt) = Torque/Radius=1.175/0.00525=223.8 N
- We Know, Width of gear (b) =[Wt / (σ_w Π m y)]
- Material Selected for Gears is SS-420, so Proof stress (0.2%) = 1344 N/ mm^2
- Allowable Tensile Stress of Material= 1344/1.5 = 896N/mm^2
- Permissible working stress(σ_w) = Allowable Stress X Velocity factor= 896 x 0.94 = 842.2 N/ mm^2
- Lewi's form factor (y) = [(0.154xZb) – 0.912] /Zb (for 20° Full depth involutes) = 0.1105
- Width of gear (b) = Wt / σ_w Π m y =1.54 mm
- If we take planet gears as 3Nos then= 1.54/3 = **0.514 mm**

The face width is same for all the planet gears of all stages. The tooth profile for all the sun, planet and ring gears is the standard involute profile.

3.0 RESULTS

3.1 Structural Analysis of Output shaft in ANSYS

- Stress developed in the Shaft due twisting and bending force are analyzed in this analysis
- Material : SS 420
- Preprocessing: Meshing:
  - Type of element : Tetrahedron
  - No. of nodes: 262440
  - No. of Elements : 181487

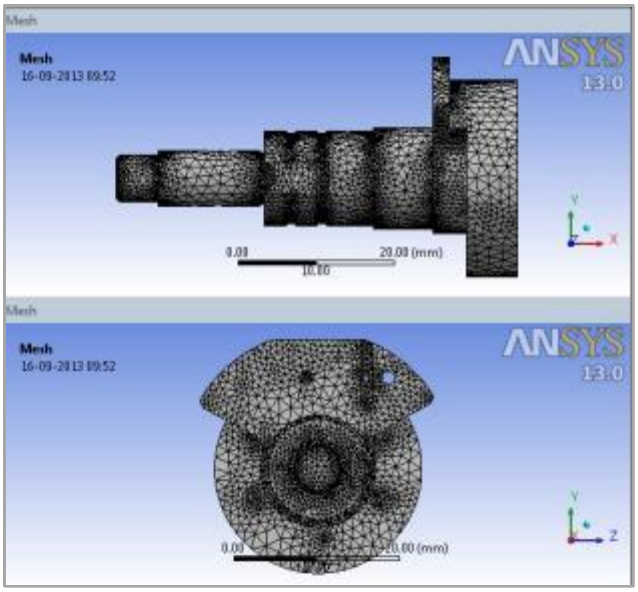


Figure 5. Meshing of Output Shaft

- The max torque of 11 Nm is impinged upon the shaft at a distance of 15 mm
- From theoretical bending & twisting moment calculations, the diameter of shaft to withstand the max. torque of 11 Nm is found to be Ø11 mm
- A load of 11 Nm is impinged upon the shaft from one end at a distance of 12 mm and the solver is run in ANSYS to get following results

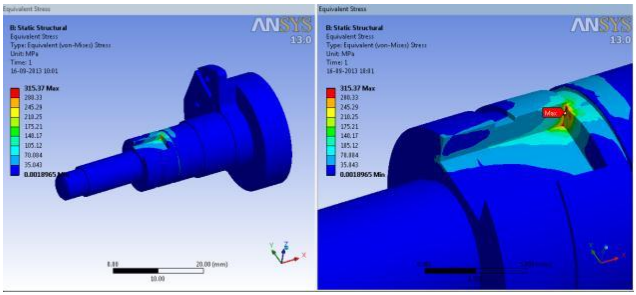


Figure 6.Equivalent Stresses-Output Shaft

Table 5. Results

Description	Value
Allowable Stress	448 N/mm2
Results in ANSYS	315.37 N/mm2

3.0 Design of Linkage Arm

Table 6. Linkage Arm Parameters

Description	Value
Power	60 W
Torque	7 Nm
Speed	33 RPM
Target Mass Lift	70 kg
Force to be lifted	70 Kg
Radius of Linkage	= T/F=7/70=0.1 m

So the radius of Linkage= 0.1 mm= 100 mm

3. CONCLUSIONS

- The model of Gears, shafts and bearings are developed in Pro-E Wildfire 4.0.
- The output shaft is analyzed using ANSYS 13.0. version and found that the design is safe
- The gearbox and motor are mounted inside a tube with screws radially
- With the obtained torque at the gearbox and with the linkage radius, the target load is proved to be lifted

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