DESIGN AND FABRICATION OF SYNCHRONIZED CLUTCH FOR AUTOMATIC SLIDING DOOR

D.L. Belgin Paul, M. Karthick, A. Sathesh Kumar
Assistant Professor, Department of Mechanical Engineering,
Vel Tech University, Avadi, Chennai, Tamilnadu, India

ABSTRACT

Clutches are device which are used to transmit power from the driver shaft to the driven shaft. Synchronized clutch is used to transmit power with very low or negligible power loss which is desirable in case of low power transmission and also it performs the general function of clutch. Torque is not controlled in this type of clutch. The slip is minimal or none. Solenoids are used to engage and disengage the clutch. Thus the operation of clutch is automatic and does not require any manual intervention. This clutch is electromechanical type and hence gaining the advantage of both. This project presents the design of synchronized clutch and also a prototype is made to test the function of clutch. “SOLIDWORKS” software is used to model the clutch and also to ensure the feasibility of manufacturing and assembly (DFMA). This type of clutch is used in low power transmission like automatic sliding door of Operation Theatres.


Cite this Article: D.L. Belgin Paul, M. Karthick, A. Sathesh Kumar, Design and Fabrication of Synchronized Clutch for Automatic Sliding Door, International Journal of Mechanical Engineering and Technology, 8(8), 2017, pp. 529–541.
http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=8&IType=8

1. INTRODUCTION

A clutch is a mechanical device that engages and disengages the power, transmission, especially from driving shaft to driven shaft. Clutches are used whenever the transmission of power or motion must be controlled either in amount or over time (e.g., electric screwdrivers limit how much torque is transmitted through use of a clutch; clutches control whether automobiles transmit engine power to the wheels). In the simplest application, clutches connect and disconnect two rotating shafts (drive shafts or line shafts). In these devices, one shaft is typically attached to an engine or other power unit (the driving member) while the other shaft (the driven member) provides output power for work.

Operation Room is an essential part of any hospital especially a multi-speciality hospital. Increased construction of hospital and operation room has raised a demand for innovation in
medical products. Generally there would be Power Backups in Multi-Speciality hospitals but there are cases where hospitals have minimum or no power backup or breakdown of power backup and there is a minimum time for power generation through power backup device. At these cases manual type of doors comes in handy as in hospital time is a critical aspect. But most of hospitals uses automatic sliding door which is easier to use with power. Some automatic sliding doors comes with a lever to be pulled while power failure. The installation of lever, the ease of pull of lever, position of lever (whether inside operation room or outside operation room or both) etc. are dependent on installation and manufacturer. Hence in case of power failure the automatic sliding door should turn into a manual door and when power comes back the manually operating door must turn back to automatic sliding door without any human intervention

Synchronized Clutch is a non-friction type clutch and has pin on the driven side and slot on the driver side. When the clutch engages the power is transmitted from slot to pin. Engagement and disengagement of clutch is based on electromechanical solenoid and when there is no power the clutch gets disengaged thus allowing manual operation. Material Selection and introduction of solenoid makes the clutch different from the other types as this clutch is cost effective and performs it function as usual. This clutch is introduced in Operation theatre automatic sliding door. With power it engages driver and driven thus making door automatic and with power failure it disengages thus making door manual.

2. DESIGN INPUT

2.1. Problem Definition
Door must work as automatic sliding door with power and in case of power failure door must become manually operating door without any external human intervention. Once the power comes it must turn back into automatic sliding door. The mechanism should be cost effective. It should be compact and should have high efficiency as this is a low power transmission

2.1.1. Door Specification
Dimensions of Door: 7 feet X 6 feet = 2133.6 X 1828 = 2140 X 1830 mm²
Weight of the Door = 120 kg to 150 Kg
Travel Distance = 12 feet = 3657.6 mm = 3660mm
Maximum Speed = 2 feet/s = 0.6096 ms⁻¹

These are the design inputs obtained from physical measurement of door and these requirements are generally required by most of the hospitals.

2.1.2. Power Calculation
Velocity V is not a constant. It varies from 0 to 0.6096 m/s. So acceleration = dv/dt = Δv/Δt = 0.6096/2 = 0.3048 (from kinematics, v = u + at). Therefore acceleration a = 0.3048 ms⁻²

Coefficient of friction between Aluminium and Nylon is assumed to be 0.04 (Once body starts moving, coefficient of friction decreases)

Acceleration due to gravity = 9.81 ms⁻²
Minimum Force required to move the object $F_{\text{min}} = \text{Friction force} + \text{Inertia Force}$

$F_{\text{min}} = \mu R_n + ma$

$= \{0.04 \times (150 \times 9.81)\} + 150 \times 0.3048$

$= 58.86 + 45.72$

$= 104.58 \text{ N}$

The Force that acts on the motor is $156.87 \text{ N}$ when FOS of 1.2 is considered.

Power = Force $\times$ Velocity $= 76.50 \text{ W}$

Thus this scenario can be considered as Low Power Transmission approximated to 80 W. Gear ratio of motor must be high enough so that the door must not be open by outsiders or anyone manually when it is functioning as automatic sliding door.

Since hospital zone is considered, the hospital door and all its related mechanism should be considered as medical device of class 3 and hence the mechanism to be designed must comply with ISO 13485.

The next stage is to develop a mechanism which suits all above requirements. SOLIDWORKS software is the design tool used in modelling the required mechanism and prototype has to be done to review and verify the design output.

3. CONCEPTUAL DESIGN

Conceptual design is the first stage of product development process once the product design specification (PDS) is confirmed. From the previous analysis (Design input) we concluded the requirements of the product. Conceptual Design is the stage where the primary concept or the outline is derived. Conceptual design is the process by which the design is initiated, carried to the point of creating a number of possible solutions, and narrowed down to a single best concept. From the number of possible solutions by using type synthesis and by evaluating ideas with respect to criteria (decision matrix) a concept is selected. That will be the basic idea of the mechanism which will be refined in embodiment and finalized in parametric design phase. Once the concept is selected the product design specification is revisited and refined if required.
3.1. Synthesis of Mechanism

Type synthesis is the process of selection of type of mechanism needed to accomplish a given requirement \(^{(5)}\). It is generally depend design factors like manufacturing process, material availability, safety, reliability, space, and economics which are outside kinematics itself \(^{(6)}\). There are six different categories like

- Lower Pairs
- Wheels, including Gears, Clutches etc.
- Cams and their forms
- Screw mechanism
- Intermittent-motion devices
- Tension and compression parts with one way rigidity

Number Synthesis is the stage where degree of freedom is considered. The degree of freedom for the required mechanism is 1 as there is one input from motor and one output required which is a sliding motion. Degree of freedom in mechanics is defined as number of output or independent movement in a mechanism.

Dimensional Synthesis is as the name specifies it boils down to solving of synthesis equation that expresses the desired motion in terms of the required unknown dimensions. These unknowns include, among other things, the link lengths, relative locations of revolute centres, and in particular for function generators, a zero or home configuration.

3.2. Decision Matrix

A decision matrix is a method of evaluating competing concepts by ranking the design criteria with weighting factors and scoring the degree to which each design concept meets the criterion. A 5 point scale (0-4) is used \(^{(8)}\). Since we know the requirement we can tabulate a table with Requirements (known) along rows and mechanism (unknown) along column. The most important requirements will be the function, cost and size. Totally useless solution is rated as 0 and excellent solution is rated as 4 \(^{(8)}\).

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Decision Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower Pair</td>
</tr>
<tr>
<td>FUNCTION</td>
<td>3</td>
</tr>
<tr>
<td>COST</td>
<td>4</td>
</tr>
<tr>
<td>SIZE</td>
<td>2</td>
</tr>
</tbody>
</table>

The scale rating is done based on field data of design engineer and manufacturer.

From the table the best mechanism is Wheels (Clutches) which matches exactly with the function requirement. Cost and size is also less when compared with other mechanism as seen above in table. Requirements like low power transmission has to be considered while considering clutches because clutches has power loss due to friction factor. Modern Single-Plate and Multi-plate Clutches has clutch plates made of compound organic resin with copper wire facing or a ceramic material. A typical Coefficient of friction used in friction disc surface is 0.35 for organic and 0.25 for ceramic \(^{(11)}\). Hence power loss will be higher. Thus we have to use electromagnetic clutch which is costlier. Thus we use synchronized clutch which is an
adaptive design (8). Synchronized Clutch is a pin and slot type clutch and transfers power between driver and driven shaft with minimum or less power loss. The Embodiment design will have the details of its configuration and parametric details like dimensions tolerance etc. Detail design will have manufacturing drawings of the same. DFMA feedback will also be attached as prototype results.

4. EMBODIMENT DESIGN

Structured development of the design concept occurs in this engineering design phase. It is the place where flesh is placed on the skeleton of the design concept. It is in this design phase that decisions are made on strength, material selection, size, shape, and spatial compatibility. Beyond this design phase, major changes become very expensive. Embodiment design is generally categorized into product architecture, configuration design and parametric design.

4.1. Product Architecture

Synchronized clutch has pin on the driven side and slot on the driver side. The power is transmitted from slot to pin. Hence the slot pushes the pin rather than pin pushing the slot. When the power shuts down the actuator pushes the clutch plate 1 away which makes the pin move away from the slot thus disengaging the clutch. When power arrives the solenoid contracts back due to electromagnetic field and the tension springs on sliding shaft (shaft 4) will pull back the clutch plate to its original position thus engaging the slot and the pin and hence engaging the clutch. Support plate which is on the driver side will also rotate along with the driven shaft in-order to maintain the alignment of driver and driven side and also to support the sliding shaft. Hence a bearing is used to make sure that the shaft doesn’t carry any stress as the driver side does not have reverse direction of rotation due to worm gear arrangement.

Figure 2 Exploited View

Figure 3 Engaged Position
This is the product architecture of synchronized clutch. The Configuration design and parametric design is as follows which deals with material selection and dimensions which is followed by manufacturing part drawings (detailed design).

4.2. Configuration Design

In configuration design we establish the general dimensions of components. Exact dimensions and tolerances are established in parametric design. The form or configuration of a part develops from its function. However, the possible forms depend strongly on available materials and production methods used to generate the form from the material. Moreover, the possible configurations are dependent on the spatial constraints that define the envelope in which the product operates. As stated in requirement the size of canopy used most commonly in hospital is 3600 mm in length, 230 mm wide and 150 mm in depth (perpendicular to paper) within which the mechanism should fit must be 120 mm in X Axis, 120 mm in Z Axis and 150 mm in Y Axis (perpendicular to plane of paper). Since it is a design input (product design specification) this design constraint should be considered as a critical aspect (also mentioned in conceptual design).

In order to calculate the general dimension of the components or parts, we need to select the material and amount of force the material can withstand (strength of the material). From design input we calculated that the force acting on the motor is 104.58 N. Considering the entire force acting on the pin, we can calculate shear stress acting on each pin as 104.58 / Cross section area of pin. Then the material can be selected accordingly based on strength, availability and cost of the material. With respect to size constraint, a standard shaft of 6 mm mild steel is considered as pin. Hence the area of pin = 28.2744 mm^2.

Shear Stress = Shear Force / Area

Area (of circle) = (π/4) x d^2

Bending Stress = Moment / Section Modulus

Moment = Force acting on shaft x Length of Shaft

Section Modulus = Centroid perpendicular to bending axis / Moment of Inertia

Moment of Inertia (for circular shaft) = (π/64) x d^4

d = Diameter of the shaft

Therefore the shear stress acting on the pin is 3.75 N/mm^2.
Bending stress will be 148.62 N/mm^2.

Principal stress = (σx + σy) / 2 + Principal Shear Stress

Principal Shear Stress = \sqrt{\left(\frac{(σx^2 - σy^2)}{2}\right) + τxy^2}

σy = 0 for circular shaft as the shaft is uniaxial loaded

Principal Shear Stress = 104.72 N/mm^2

Principal Stress = 179.03 N/mm^2

Considering a Factor of safety of 1.2, Maximum Principal tensile stress acting on the shaft is 214.836 N/mm^2 and Maximum Principal Shear stress is 125.664 N/mm^2

Stainless steel AISI 304 has a Yield Strength of 215 N/mm^2.

From theory of failures \(^{(1)}\) considering Von Mises theory for ductile materials, Von Mises stress for uniaxial material is \(σ = \sqrt{(σx^2 + 3τxy^2)} = 148.66\) N/mm^2

Thus the yield strength is greater than Von Mises stress with a factor of safety of 1.446. Thus strength of material is greater than stress of material and hence Mild Steel BIS 513 can be selected \(^{(12)}\). When considering availability and cost of the material, Mild Steel BIS 513 is readily available and economic. Since the selected material falls inside the requirement, this material can be selected.

We have to note that critical area has been considered for stress calculation. And the case we considered is when the entire force acts on single pin which has very less possibility as the support plate keeps track of alignment of driver and driven shafts within tolerance limits. Thus even with critical situation is considered the material selected is safe in operating zone. Non critical areas are considered as Mild steel BIS 513 due to the reason of its higher availability, cost effectiveness and easier to manufacture. Delrin 100 material is M4 tapped and guided into the screw thus making it a 6 mm shaft in-order to reduce noise and vibration during engagement of slot to the pin where Delrin acts as a damper absorbing some amount of energy. Delrin 100 is also readily available, cost effective and easy to manufacture. Total size is considered in such a way that the dimension of synchronized clutch falls inside the required size as given in design input (canopy size). SOLIDWORKS software is used as a 3D CAD tool for configuration design.

4.3. Parametric Design

In configuration design the emphasis was on starting with the product architecture and then working out the best form for each component. Qualitative reasoning about physical principles and manufacturing processes played a major role. In parametric design the attributes of components identified in configuration design become the design variables for parametric design. A design variable is an attribute of a part whose value is under the control of the designer. This typically is a dimension or a tolerance, but it may be a material, heat treatment, or surface finish applied to the part. This aspect of design is much more analytical than conceptual or configuration design. The objective of parametric design is to set values for the design variables that will produce the best possible design considering both performance and cost.

First step of parametric design is to consider the solution evaluation parameters (SEP’s) which should be traced back to product design requirement or design input. As noted in conceptual design these SEP’s are Function, cost and size. As far as synchronized clutch is
considered, it function and size has been within design constraint. The total cost of synchronized clutch is based on material and manufacturing cost and the cost should be less than 80W Electromagnetic clutch which is more than 150 USD. As the general dimension has been done in configuration design, the finalization of size, providing geometric tolerance, fits and DFMA should be emphasized in parametric design.

The BOM of the synchronized clutch is as follows

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>MATERIAL</th>
<th>Surface Finish</th>
<th>QTY.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coupler 1</td>
<td>Mild Steel BIS 513</td>
<td>Zinc Plating and Powder Coating</td>
<td>1</td>
</tr>
<tr>
<td>Shaft 1</td>
<td>Mild Steel BIS 513</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Clutch Plate 1</td>
<td>Mild Steel BIS 513</td>
<td>Zinc Plating and Powder Coating</td>
<td>1</td>
</tr>
<tr>
<td>Shaft 3</td>
<td>Delrin 100</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Clutch Plate 2</td>
<td>Mild Steel BIS 513</td>
<td>Zinc Plating and Powder Coating</td>
<td>1</td>
</tr>
<tr>
<td>Shaft 2</td>
<td>Mild Steel BIS 513</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Support Plate</td>
<td>Mild Steel BIS 513</td>
<td>Zinc Plating and Powder Coating</td>
<td>1</td>
</tr>
<tr>
<td>Shaft 4</td>
<td>Mild Steel BIS 513</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Coupler 2</td>
<td>Mild Steel BIS 513</td>
<td>Zinc Plating and Powder Coating</td>
<td>1</td>
</tr>
<tr>
<td>Bearing</td>
<td>Standard</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Spring</td>
<td>Spring Steel</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>M4 X 0.7 X 8 SS Hexagon Socket Cap</td>
<td>Stainless Steel AISI 304</td>
<td>NA</td>
<td>4</td>
</tr>
<tr>
<td>M4 Washer</td>
<td>Stainless Steel AISI 304</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Circlip</td>
<td>Mild Steel BIS 513</td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>

Mild steel BIS 513 is considered as the material for less critical areas as stated before. Standard bearing is used with ID 6 mm, OD 15 mm and thickness 5 mm. This bearing is chosen due to the dimensional constraint of internal shaft, thickness of material and size of canopy. Medium class tolerance for linear dimension is provided according to ISO 2768. For the reason of easier assembly and accuracy of position insert welding is used instead of face welding or butt welding (DFMA). Since there is a sliding joint in the synchronized clutch a clearance fit has to be given between slider shaft and clutch plate 1. For bearing press fit has to be given. The circular runout of driver and driven shaft, driver and driven coupler has to be as minimum as possible. M4 Cap screws has been used as pin shaft with Delrin 100 having thread with standard pitch 0.7. M4 Cap Screws is as per ISO 4762. Extension springs are used to pull back the clutch plate and engage the clutch when power arrives. This Extension Springs has 9 mm in un-extended state and 15 mm while extended. Circlips are used as a stopper to avoid further extension of spring. The stroke length of solenoid is chosen in such a way that the extended length of the spring is 15 mm max thus producing no stress to the clutch plate and spring. All the dimensions are provided to the components using SOLIDWORKS software and manufacturing drawing is made. Interference analysis is made in SOLIDWORKS software excluding standard components like spring, M4 Screw and Bearing. And the result is as shown in below picture.
No Interferences has been detected. Hence there are no interference fit and overlap of parts.

Since we theoretically calculated the stress acting on pin, we will also calculate the stress acting on clutch plate and its displacement considering maximum force is acting in only one slot with all slots free from force (the critical situation). For Mild Steel BIS 513, the following result has been obtained in SOLIDWORKS:

Thus the maximum Von Mises Stress acting in Clutch Plate is 9.295 N/mm² and maximum displacement is 6.547 X 10⁻⁴ mm. Thus a circular face out of ±0.001 is more than suffice for maximum displacement and greater accuracy can be achieved.
Thus all design requirements are met by synchronized clutch by considering material, dimension and tolerances as design variables and also considering design constraint like size of canopy, low power wastage, cost of clutch and functional requirement. Thus the end result of parametric design leads to 3D components from which 2D Manufacturing drawings are to be produced and sent to manufacture to make a prototype which has to be reviewed and verified. Any DFMA feedback given by manufacturer should be updated next revision of drawing so that manufacturing and assembly becomes simpler, less time consuming and cost effective. If possible revised design could be prototyped. The feedback from manufacturer has been added in 10.1 section and has been implemented in the prototype.

5. DETAIL DESIGN
In this phase the design is brought to the stage of a complete engineering description of a tested and producible product. Missing information is added on the arrangement, form, dimensions and tolerances, surface properties, materials, and manufacturing processes of each part. This results in a specification for each special-purpose part and for each standard part to be purchased from suppliers. Detailed Engineering Drawings suitable for manufacturing is prepared. Routinely these are computer-generated drawings, and they often include three-dimensional CAD models. Verification testing of prototypes is successfully completed and verification data is submitted. All critical-to-quality parameters are confirmed to be under control. Assembly drawings and assembly instructions also will be completed. The bill of materials for all assemblies will be completed. Decisions on whether to make or to buy from an external supplier will be made. A detailed cost estimate for the product will be carried out. These are the activities of Detailed Design.

From SOLIDWORKS 2D drawings are drafted for manufacturing purpose. The drawing format contains information like Title, Drawing No, Revision and Version Number, Material, Finish, Next Assembly number, Document Type, Scale, Sheet Number and Linear Tolerance Box as per ISO 7200 and the drawing paper is as per ISO 5457. First angle of projection is used as per European View.

From the bill of material we can figure out the standard components. The standard components will be Bearings, Screws, Circlips and Washers (if required). The parts to be manufactured are Driver Shaft, Driven Shaft, Driver Coupler, Driven Coupler, Clutch Plate 1, Clutch Plate 2, Support Plate, Sliding Shaft, Delrin Enclosure which makes pin shaft, Extension spring. Hence manufacturing drawing for the above said components has been made. Surface finish is Zinc Plating with or without powder coating as there is a requirement that the synchronized clutch should be free from rust and corrosion since it is used in hospital environment. Assembly drawing and assembly instructions are provided.

Prototype is made with the help of manufacturing drawings and it is reviewed and verified. Bill for prototype indicates that the cost of the Synchronized clutch is Rs 800 which is equal to 11.75 USD as on Month of January 2017. Please note that this is R&D Costing. Production cost will be even less when compared with prototype cost as production cost is based on volume. ISO 13485 is considered during design phase of synchronized clutch.

6. DESIGN OUTPUT
The following are the design output of synchronized clutch

- The Synchronized clutch is capable of changing automatic sliding door to manual sliding door and back to automatic sliding door without human intervention with respect to power availability.
The size is compact enough to fit inside the canopy of sliding door

- The synchronized clutch is cost effective
- It is efficient in transferring power from driver to driven shaft
- Stainless Steel, Mild steel and Delrin are the material used which are available and cost effective
- 2 mm Gap is considered as disengaged space
- Delrin Enclosure if damaged can be replaced easily
- DFMA is analysed and manufacturing feasibility is considered before prototyping
- No interference or overlaps of parts
- Von Mises Stresses are lesser than Strength of the material and displacement is in the order of 65 microns
- 619/6 Bearing is selected with ID 6 mm OD 15 mm and thickness 5 mm
- Manufacturing Drawings, Assembly Drawings and Bill of materials has been produced

7. PROTOTYPE

Prototype is presented
8. CONCLUSIONS
Thus the Design and Prototyping of Synchronized clutch for automatic sliding door has been done. All specifications mentioned in product design specification are met. The Synchronized clutch is useful in converting the automatic sliding door to manual and vice versa with respect to power and without human interference and it is very much useful in low power transmission system.

9. LITERATURE SURVEY
- Mr. Vishal J. Deshbhratar, Mr. Nagnath U. Kakde, 2013, Design and Structural Analysis of Single Plate Friction Clutch
- Jeyakkannan , Shankar vigne s , Prakash A , Subashnandha K , Purushothaman P, 2016 Electromagnetic Clutch
- https://Manual_transmission#Dog_clutch
- https://Non-synchronous_transmission
- http://www.mecholic.com/2016/01/friction-clutch-types-applications-material-used.html

REFERENCES
Design and Fabrication of Synchronized Clutch for Automatic Sliding Door


[18] General Tolerance ISO 2768
[19] ASM Material Data Sheet AISI 304
[21] Hexagonal Socket Cap Fastener ISO 4762 DIN 912
[22] SKF Roller Bearing Catalogue, Deep groove Ball Bearing
[23] ISO 7200 technical product documentation data fields in title blocks and document headers
[24] ISO 5457 technical product documentation sizes and layout of drawing sheets