International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 7 Issue 12 Ver I || Dec 2018 || PP 16-21

Design, Fabrication & Simulation of a Semi-Rigid Helicopter Swashplate Control Mechanisms

Yograj Sonar[1], Dr. S. Sivakumar[2]
[1](Aeronautical Engineering, Bharath Institute of Higher Education and Research, Chennai-73, India)
[2](Aeronautical Engineering, SRM Institute Of Science And Technology, Chennai, India)
Corresponding Author:Yograj Sonar

Abstract:*This project work deals with the indigenous design, fabrication, assembly and simulation of a semi-rigid helicopter main rotor swash-plate mechanism and its components. Initially Pencil-paper drawings and wooden structure have done to fix the correct dimensions for swash plate components and structural members. All the necessary components to operate a semi-rigid helicopter main rotor with swash-plates are fabricated and assembled. The components are cyclic & collective pitch assembly, swash-plate assembly, rotor head assembly etc. All the three assemblies, connecting with one another (individual components), give the desired output and have been investigated. The design analysis of gear/pulley diameters and rpm of the transmission system have been done and the simulation is performed in CATIA V5. Demonstration of the swash-plate operation is done constructing a single seat helicopter structure. However, this model helicopter structure and control mechanism parts are self-designed and fabricated, which are not resembled any other helicopters control mechanism. The outcome of this project gives the details about indigenous manufacturing of swash plate control mechanism for a semi-rigid helicopter operation.*

Keywords*-Analysis & Modeling, Construction, Transmission, Swashplate*

Date of Submission: 28-11-2018 Date of acceptance: 13-12-2018

I. Introduction

The swashplates assembly is the key mechanism to control the pitch angles of a helicopter blades. The pitch anglesare controlled directly from the control unit (cyclic & collective assembly) and the swashplates act as moderator. The lower (stationary) swashplate takes input from the cyclic and collective assembly through control rods and transmits changes to the upper (rotating) swashplate. Lower & upper swashpltes are separated by means of a ball bearing. The upper swashplate gives the output to the blades through pitch links. All the semi-rigid helicopters are two bladed and all the two bladed helicopters have feathering and flapping motions but no lead-lag motion.

Actuating mechanism of a helicopter, also known as swashplate, is part of helicopter's power generating module which transfers the control commands of the actuators to the rotating blades[1]. The cyclic movements are somewhat morecomplicated because they tilt the whole rotor system left, right, fore and aft. This requires universal joint movement of the swashplate. The non-rotating part moves in the same direction as desired rotor movement[2].

In summary, the design and analysis are performed with the help of pencil-paper drawing and CATIA V5 software. For some small controlling parts, it is difficult to get the appropriate dimensions and so to get the approximate dimensions one wooden structure is built which became helpful to complete the desired corrections. The measurements of all the designed controlling parts are not copied from any existing helicopter**;** so it is the prime challenging step to proceed the project. Finally, the project gives the details to manufacture the swashplate with the helicopter structure. The complete helicopter structure with control components is shown in figure-1.

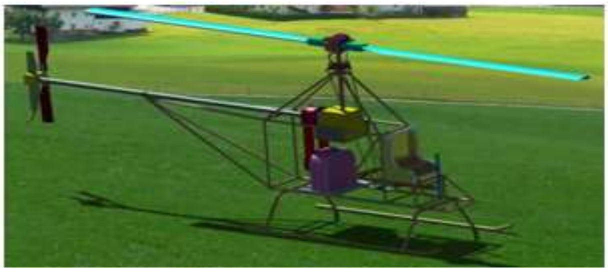

Fig-1: Helicopter structure with components

II. Design& specification

First of all, the design part gives the details about measurements of the required components of the project model. The design part includes some steps-

A. Pencil-paperdrawing

To start the work the model and components are self- analyzed based on semi-rigid helicopter mechanical flight control mechanism and drawn. Control unit & rotor head components assembly is shown in figure-2.

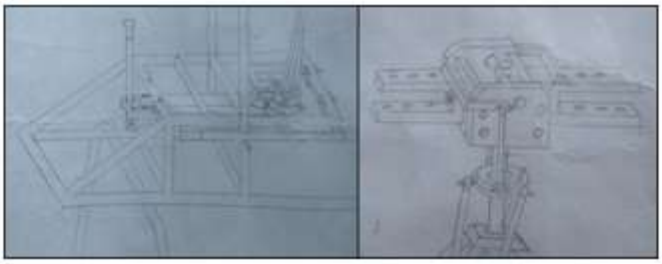

Fig-2: Control unit & rotor head assembly

B. Wooden structure

The wooden structure is built to get the approximate measurements, mainly the small components. The tools required for the wooden structure are-

a. Round woodensticks
b. Hammer
c. Ironpins
d. Cloth & Material measuringtaps
e. Hacksaw
f. Electric pipesetc.

C. CATIA V5 part design &assembly

The parts are designed in CATIA V5 to reduce the pressure of fabrication. It is done based on final assumed dimensions which are taken with the help of drawing and wooden structure. All the necessary parts are designed and assembled respectively as shown in figure-3.

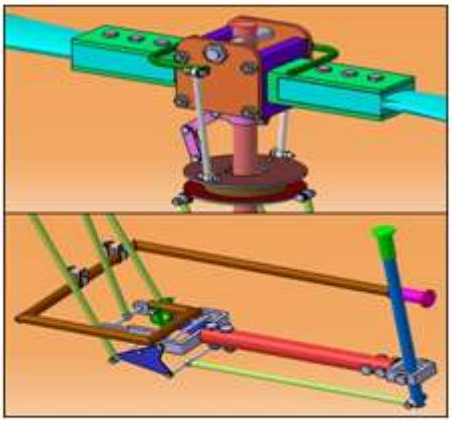

Fig-3: Cyclic-collective & rotor head assembly

In this step the measurements of the components of the target model are assumed.

Name of the component	Height (mm)	Length (mm)	Width (mm)	Diameter (mm)
Frame & Skids				
Frame (tubular construction)	1800 (excluding main rotor)	3500 (excluding tail rotor distance)	400	Outer dia 25mm (thickness 3mm)
Skids (tubular construction)	500	2100	1000	Outer dia30 (thickness 5mm)
Control unit				
Cyclic		500		25
Collective		700		25
Cyclic-collective connector		500		50(outer, thickness 5)
Coupling		300		
Belcrank		120		
Fork assembly		140		
Back sided Connecting rods		1400		20
Forward connecting rod		1320		20
Swashplate assembly				
Lower swashplate				Outer-200 Inner-80
Upper swashplate				Outer-200 Inner-50
Upper scissor elbow		100		
Lower scissor elbow		100		
Scissor clamp				40
Rotor head assembly				
Blade grip	70	220	100	
Pitch links		200		
Feathering bearing				Outer-66 Inner-20
Rotorouter plate(th-10)	160		160	
Rotorinner plate(th-25)	140		140	Hole dia 70

Table-1: Finalized measurements of parts

III. Gear/pulley rpm calculation

The target model has two destinations: physical model swashplate control test & CATIA simulation (rpm reduction). So, the mechanism of the main rotor swashplate (tilting, rotating, motion etc. with respect to control unit inputs) is shown physically and on the other hand, rpm/diameter of gears and pulleys are calculated and demonstrated with the help of CATIA V5 software workbench. Simulation (rotation of gears & pulleys) is alsodone.

Generally a helicopter main rotor rpm is known as 1/7 of engine rpm. But in lightweight or semi-rigid helicopters 1/6 or 1/5 reduction is alsoapplicable.

For example: R22 semi-rigid helicopters rpm-
Engineshaftrpm = 2652(at maxspeed)
Mainrotorrpm = 530
Rpm reduction ratio = 530:2652 = 1:5
Similarly, 1/5 reduction is chosen for demonstration in CATIA simulation as shown in figure-4.

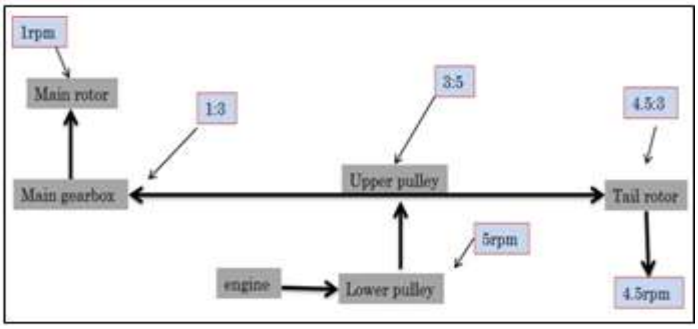

Fig-4: rpm reduction/increasing chart

Note: The first number of each ratio indicates the output rpm.

Generally, the function of the main and tail rotors are same but the tail rotor speed is higher (more than 3×) than the main rotor speed because,

Tip speed=radius×rpm (Where, rpm=angular velocity)

A. Pulley rpm-diameter relationship

The rpm-diameter relationship of a pulley is given as-

$$\mathbf{(lower\ pulley)_{diameter} \times (lower\ pulley)_{rpm} = (upper\ pulley)_{diameter} \times (upper\ pulley)_{rpm}} \quad \text{--- (1)}$$

B. Gear rpm-diameter-teeth relationship

The rpm-diameter-teeth relationship of a gear is given as-

$$\mathbf{\frac{(gear2)_{rpm}}{(gear1)_{rpm}} = \frac{(gear1)_{diamter}}{(gear2)_{diamter}} = \frac{(gear1)_{teeth}}{(gear2)_{teeth}}} \quad \text{--- (2)}$$

gear1=driving gear, gear2=driven gear

Pulley:

Let, lower pulley diameter=100mm

So applying equation (1)...

$100\times5=(\text{upper pulley})_{\text{diameter}} \times3$

$(\text{upper pulley})_{\text{diameter}} = 166.667\text{mm}$

Main Gearbox:

Let, driving gear diameter=100mm

$$\frac{(\text{gear }2)_{\text{rpm}}}{(\text{gear }1)_{\text{rpm}}} = \frac{(\text{gear }1)_{\text{diamter}}}{(\text{gear }2)_{\text{diamter}}}$$

$$\frac{1}{3} = \frac{100}{(\text{gear }2)_{\text{diamter}}}$$

$(\text{gear2})_{\text{diamter}} = 300\text{mm}$

Tail Gearbox:

Let, the driving gear of the tail rotor(gear3)=80mm

$$\frac{(\text{gear }4)_{\text{rpm}}}{(\text{gear }3)_{\text{rpm}}} = \frac{(\text{gear }3)_{\text{diamter}}}{(\text{gear }4)_{\text{diamter}}}$$

$$\frac{4.5}{3} = \frac{80}{(\text{gear }4)_{\text{diamter}}}$$

$(\text{gear4})_{\text{diamter}} = 53\text{mm}$

So, Lower pulley diameter = 100mm

Upper pulley ,, = 166.667mm

main driving gear ,, = 100mm

main driven gear ,, = 300mm

tail driving gear ,, = 80mm

tail driven gear ,, = 53mm

Gear Teeth Calculation:

However, the gear teeth can be calculated using equation (2)...

$$\frac{(\text{gear }1)_{\text{diamter}}}{(\text{gear }2)_{\text{diamter}}} = \frac{(\text{gear }1)_{\text{teeth}}}{(\text{gear }2)_{\text{teeth}}}$$

Gear1has 30 teeth, using formula...

$$\frac{100}{300} = \frac{30}{(\text{gear }2)_{\text{teeth}}}$$

$(\text{gear2})_{\text{teeth}}$ **= 90**, it means if gear1 revaluates 3 times the gear2 revaluates 1 time.

Gear3 has 45 teeth, using formula...

$$\frac{80}{53} = \frac{45}{(\text{gear }4)_{\text{teeth}}}$$

$(\text{gear4})_{\text{teeth}}$ **= 30.**

The gear diameter can be reduced by increasing the number of teeth.

IV. Fabrication & construction

First of all, a small single seat helicopter frame is built in tubular construction (refer specification) in the condition of semi-rigid helicopter. Considering high strength to weight ratio, each tube was cut, fitted and welded by arc welding.

The components of control unit assembly, the swashplate assembly and the rotor head assembly are made with the help of lathe machining.

As a whole, the fabrication process was completed in cutting, machining, welding etc. processes. The fabricated structure & components with assembly installation is shown in figure-5.

Fig-5: physical target model

V. Simulation

Three rpm reduction/increasing assemblies are-

A. **Pulley**

Lower pulley is attached to the engine, so too much reduction to the upper pulley may cause vibration. So diameter difference between the upper & lower pulleys also not too much. Therefore the pulleys rpm reduction ratio is 5:3, i.e., if lower pulley rotates at 5 rpm the upper pulley rotates at 3rpm.

B. **Main gearbox**

The main driving shaft is attached to the upper pulley and it transmits the power & torque output to the main & tail gear boxes. The main gearbox has rpm reduction ratio (3:1).

C. **Tailgearbox**

Where the tail gearbox has rpm increasing ratio(3:4.5).

The simulation of gear rpm reduction/increasing is shown in figure-6.

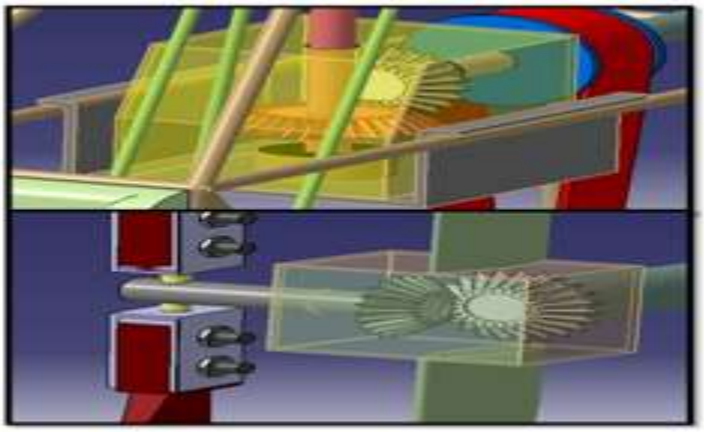

Fig-6: Gears rpm simulation

VI. Result &Discussion

The physical models control mechanism is tested by sitting on the pilot seat and the main aim of the physical model is to show the swashplate tilting with respect to the cyclic and collective controls and the response of the swashplate to the pitch angle changes. Pitch changes are occurred on the blade grips. The output of the input commands given in the control inputs of the physical model are given bellow-

Degrees of freedom	Motion	Control unit	Response of swashplate
Vertical	Altitude	Collective pitchlever	Moves up
Longitudinal	Pitching (forward& backward)	Cyclic pitch lever	Tilts forward & backwards
Lateral	Rolling (sideways)	Cyclic pitch lever	Tilts sideways

Table-2: Physical model output

The simulation of the designed model represents the swashplate operation and the rpm reduction increasing to the main rotor and tail rotor respectively. Simulation of the whole swash plate assembly and rpm reduction have been done in CATIA. The simulated data shows the rpm reduction of the target model in CATIA.

Engine rpm	Lower pulley rpm	Upper pulley rpm	Driving gear rpm	Driven gear rpm	Mainrotor rpm
5	5	3	3	1	1

Table-3: Simulation model output

The simulated data is for a normal semi-rigid piston engine helicopters gear/pulley rpm reduction. So when the engine crankshaft is rotating at 5rpm the main rotor will be rotating at 1rpm. Similarly when the helicopter will be in normal flight, the main rotor rotates around 350rpm and so engine will be rotating at 5×350= 1750rpm.

VII. Conclusion

In this paper physical demonstration of the main rotor swashplate control mechanism by moving helicopter control has been done. The helicopter structure with swashplate controls has been built in CATIA V5. In simulation, the rpm reduction/increasing & power transmission of belt drive, pulleys and gears are demonstrated. The cyclic & collective controls give output as the directional and vertical motion of the swashplate respectively, resulting in pitch change of the rotor blades. All of the mechanism components are of unique measurements and uniquely arranged in the condition of semi- rigid helicopter. The measurements and rpm transformation of the designed model is applicable for a new piston engine helicopter design.

Acknowledgements

The target model is successfully completed with the help of guide, Dr. S. Sivakumar's pieces of advice in the project journey and financial support from my brother, Dilip Kumar Sonar.

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Yograj Sonar"Design, Fabrication & Simulation of a Semi-Rigid Helicopter Swashplate Control Mechanisms"International Journal of Engineering Science Invention (IJESI), vol. 07, no. 12, 2018, pp 16-21