DESIGN OF CONCENTRIC DRIVEN SERIAL CHAIN ROBOT WRIST

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

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In

Mechanical Engineering

BY

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C E R T I F I C A T E

This is to certify that the work in thesis entitled **"DESIGN OF CONCENTRIC DRIVEN SERIAL CHAIN ROBOT WRIST"** submitted by **Mr. Rohit Kumar Singh (108ME047)** in partial fulfillment of the requirements for the award of **Bachelor of Technology degree** in the department of Mechanical Engineering, National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the work reported in this thesis is original and has not been submitted to any other University/Institute for the award of any Degree or Diploma.

He bears a good moral character to the best of my knowledge and belief.

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ABSTRACT

Robots wrist configurations existing till today are either remotely actuated or by attaching driving mechanism directly to the joint. Human wrist has a special advantage of having the muscles powering it located in the forearm, resulting in its small size, but the robots wrists are larger in size due to the existing constraints of powering source to be located within the wrist itself. To overcome this constraint, for applications of robots in surgical application, defense, nuclear industry etc scientists are working towards developing wrists of smaller sizes. In continuation of this effort towards developing miniaturized wrists, this project aims to design a wrist that's remotely actuated & being operated by a single motor, leading to reduction in overall size of the wrist. This design is used to develop 3-DOF wrist with remote actuation of Y-P-R motion using single motor & various sets of Bevel gear arrangements & clutches.

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List of abbreviations

Sl no	Abbreviation	Acronym
1.	I/P	Input
2.	FSEM	Fail safe electromagnetic clutch
3.	BG1	Bevel gear 1
4.	BG2	Bevel gear 2
5.	PC2	Pitch Cylinder 1
6.	PC2	Pitch cylinder 2
7.	RR Clutch	Roller Ramp Clutch
8.	MEM	Magnetic Engagement Mechanism

Chapter 1

1. *INTRODUCTION*

In conventional six axis robotic arm, three of the six axes are in the wrist. Three degree of freedom robotic wrist are employed in nuclear industry, industrial robots etc that requires precision, dexterity & simplified master slave interfacing. But simpler tasks employ two or even less degree of freedom. Conventional robots employing six degree of freedom arm with three degree of freedom wrists are remotely actuated using sets of gear train & motors. Motors can be mounted with proper gear reduction unit in each link to drive the joint but this kind of arrangement would lead to motors & gear reduction units to be located onto wrists sub-assembly leading to increase in inertia load to the motors driving the arm subassembly .So remote actuation is generally preferred.

Mechanical Transmission mechanism employed to transmit motion from actuator to the joints involve epicyclic gear trains, push rod linkages & tendon drives. Epicyclic gear drives are commonly used for speed reduction & torque amplification in mechanical systems. Bevel gear wrist mechanisms are have been incorporated in most industrial robots because they are simple & compact in size, can be sealed in metallic housing that keeps the gear train free of contamination & can be produced economically & reliably. Furthermore using bevel gear trains for power transmission, actuators can be remotely mounted on the forearm, thereby reducing weight & inertia of robot manipulator.

Since a wrist generally requires a three degree of freedom to located the end effecter to an arbitrary position, so it is required to have minimum of three independent rotations about three non-coplanar intersecting joint axes. To achieve such a motion with gearing, three degree of freedom bevel gear train of gyroscopic complexity is required.

In general good robotic wrist should possess following properties:

1. Three degree of freedom
2. Spherical motion
3. Large workspace
4. Remote drive capability
5. Compact size, light weight & low inertia
6. High accuracy & repeatability
7. High mechanical Stiffness
8. Low manufacturing cost
9. Rugged & Reliable design

In order to gain advantage over existing robot wrists, this project aims at reducing size, low manufacturing cost, light weight, inertia etc. Since reducing number of motors & remote actuation would provide an extra advantage, hence project solely aimed at fulfilling present needs of industry.

(1, 2)

1.1 *Types of wrist mechanism(1,2)*

Wrist mechanism can be classified in several ways depending on degree of freedom, types of motion & other geometrical considerations etc.

Depending on classification of types of joint, a wrist is said to be spherical wrist if its joint intersect at a common point otherwise it is called non-spherical wrist.

Depending on types of geometrical considerations wrist can be classified as simple, if angles between adjacent joint axes are ±90, otherwise if any of the twist angles are not equal to ±90, then it is called as oblique wrist.

Wrists mechanisms can also be classified depending on types of gearing arrangement. A wrist is called basic mechanism if rotations of the input link are transmitted to the articulation points by gear mounted only on the articulation axes & it is called derived mechanism if additional idler gears are incorporated at the articulation points.

1.2 *Wrist actuators(1,2)*

With the demise of Hydraulic robots, virtually wrists are generally powered by Electric motor. Robotic wrist actuators are classified into two categories depending upon orientation of their axes: Pitch-Yaw-Roll wrists like the human wrist & Roll-Pitch-Roll wrists. These terms i.e. Roll, pitch & yaw resembles to human wrist kinesiology terms of flexion/extension, radial ulnar deviation & supination/pronation. The two types are shown below.

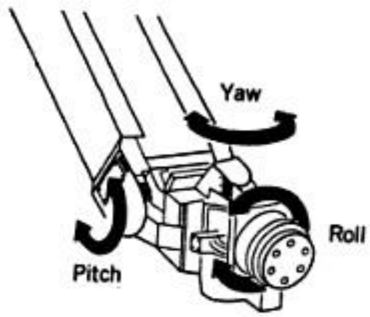

Fig 1- Pitch-Roll-Yaw Wrist(1,2)

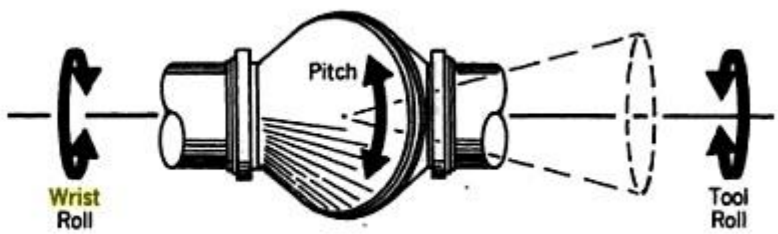

Fig 2: Roll-Pitch-Roll Wrist (1, 2)

1.3 *Motivation*

At the beginning of all civilized societies, nearly all production and effort was the result of intensive human labor. When mechanical methods of performing functions were discovered and complex mechanisms were developed, the need for human labor was reduced. Repetitive functions such as lifting water and grinding grain were replaced, and other tasks slowly gave way to the more resilient strength of machines. Technological advances soon paved the way to even more complex machines and today, commercial and industrial robots are used universally and extensively, specifically in the fields of manufacturing, assembly and packing, transport, earth and space exploration, surgery, weaponry, laboratory research, and mass production of consumer and industrial goods.

With increasing advancement in Industrial robots & replacement of most of the labor intensive works with robots, scientists are working towards a goal of making robots almost similar to Humans in every respect. The main approach of scientists in present days for wrist design is to bring driving units of wrist to away from it & just having moving parts in wrists.

1.4 *Objective*

1. To Study different existing robot wrist configuration.

2. To propose different mechanism to solve the aim of remote actuation of concentric driven three degree of freedom wrists.

3. To propose a design corresponding to our aim.

4. To check feasibility of the prepared design, considering various factors like economy, size, manufacturability etc.

5. To prepare final design considering various factors like feasibility & after removing shortcomings in previous design.

6. To prepare 3D model of the proposed design, that can be used for manufacturing.

1.4Organization of the thesis

The entire thesis is divided into 6 chapters.

Second chapter consists of Literature survey. Various works in the field of Robot's wrist are studied & presented. Wrist designs existing in applications ranging from medical to industries were studied & taking into consideration of wrists manufactured by different companies like ABB, Funac etc, a design of particular capacity & application was chosen for final design.

Third Chapter consists of various mechanism, joints & designs proposed for fulfilling the desired objective. It includes all possible mechanism through which remote actuation of 3DOF wrist can be achieved using a single motor.

Fourth Chapter consists of descriptions for the final design prepared taking into considerations of various factors like economy, size, manufacturability, feasibility etc. This chapter includes descriptions of every component used in Final 3D model & using this as the base design, it can be directly employed for manufacturing.

Fifth chapter gives details regarding various products that are required for preparing a final model with details mentioned side by side, to manufacture robot wrist for particular configuration & application as selected during literature survey.

Sixth Chapter consists of results & discussion regarding the final model of the project discussing advantages as well as disadvantages of the proposed model.

Chapter 2

Literature survey

Year	Author	Journal,vol. page	Theoretical/analytical/experimental/stastical	Software used	Method used	Material & machine use or source of data (for analytical)	Major Findings
1987	K C Gupta	IEEE,55	Theoretical & mathematical	NA	Not specified	Data collected from existing robots configurations	For computer control of Robot wrists,closed form equations are required.So it was derived for orthogonal & non orthogonal co-intersecting axes.
2003	Meng li,Tian Huang,Zhanxian li	IEEE,6	Theoretical & mathematical	NA	Matrix Transformation	Previous research	Using Principle of Motion differential ,3 DOF Wrist design was presented ,which had minimum number of parts & large orientation capability
1995	Richard A Nellums	US Patent number 5460060	Theoretical	NA	NA	Previous research	Shifting mechanism for a gear change transmission.
1983	Kwang Yew	US Patent number 4397380	Theoretical	NA	NA	Previous research	Design of Failsafe EM CLutch

Chapter 3

3-Identification of Different Mechanism & its associated joints for the Design

3.1 Identification of the joints and its type:

As proposed in the design, revolute joint was to be used for providing Yaw-Pitch-Roll motion, so it was solved using single motor driven gear train arrangement.

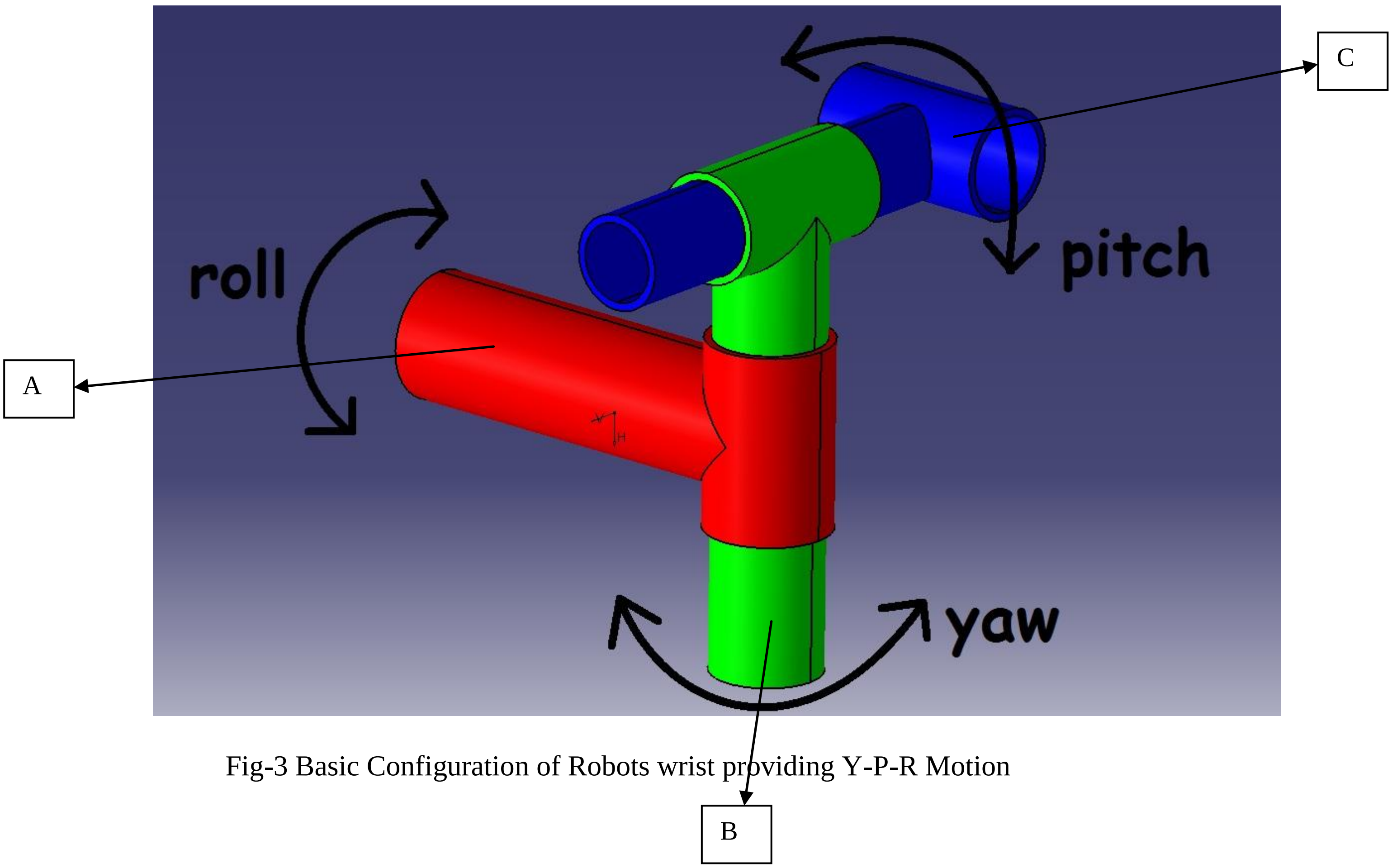

Fig-3 Basic Configuration of Robots wrist providing Y-P-R Motion

To transmit the power from the single motor, a splinted shaft is mounted over the motor so as to hold a special gear assembly which at the same time can reciprocate over the shaft, actuating the gears to further transmit the power to their respective revolute joints.

The gear assembly consists of two bevel gears and a spur gear as shown.

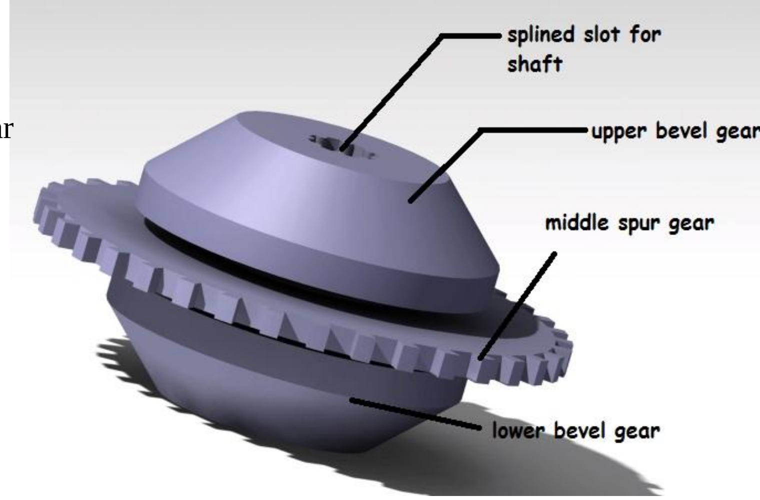

Fig 4: Gear assembly to provide three Motions

- Upper bevel gear: Engages with the bevel gear attached to the shoulder joint enabling the shoulder to move along with the base motor, irrespective of other joints.
- Spur gear: Engages with the inner toothed spur gear which enables the whole arm which hold the manipulator assembly and moves according to the base motor when selected.
- Lower bevel gear: Engages with the bevel gear mounted in the base which in return revolves the gear attached to it which drives a belt, moving the final gear drive attached to the elbow via an independent intermediate gear assembly.

Since use of gear shift mechanism could solve the problem, but associated noise & vibration with the gear change can inhibit the joint from being practically implementable. So a design similar to above mentioned was proposed with the difference that instead of gear change, piezoelectric gripper would be attached at three places of the long shaft attached with the motor & whenever each motioned would be desired, these grippers would be allowed to mate with main shaft & particular motion would be produced. Piezoelectric gripper was preferred due to size constraint of the wrist.

3.2: Design based on basic proposed joints & mechanisms

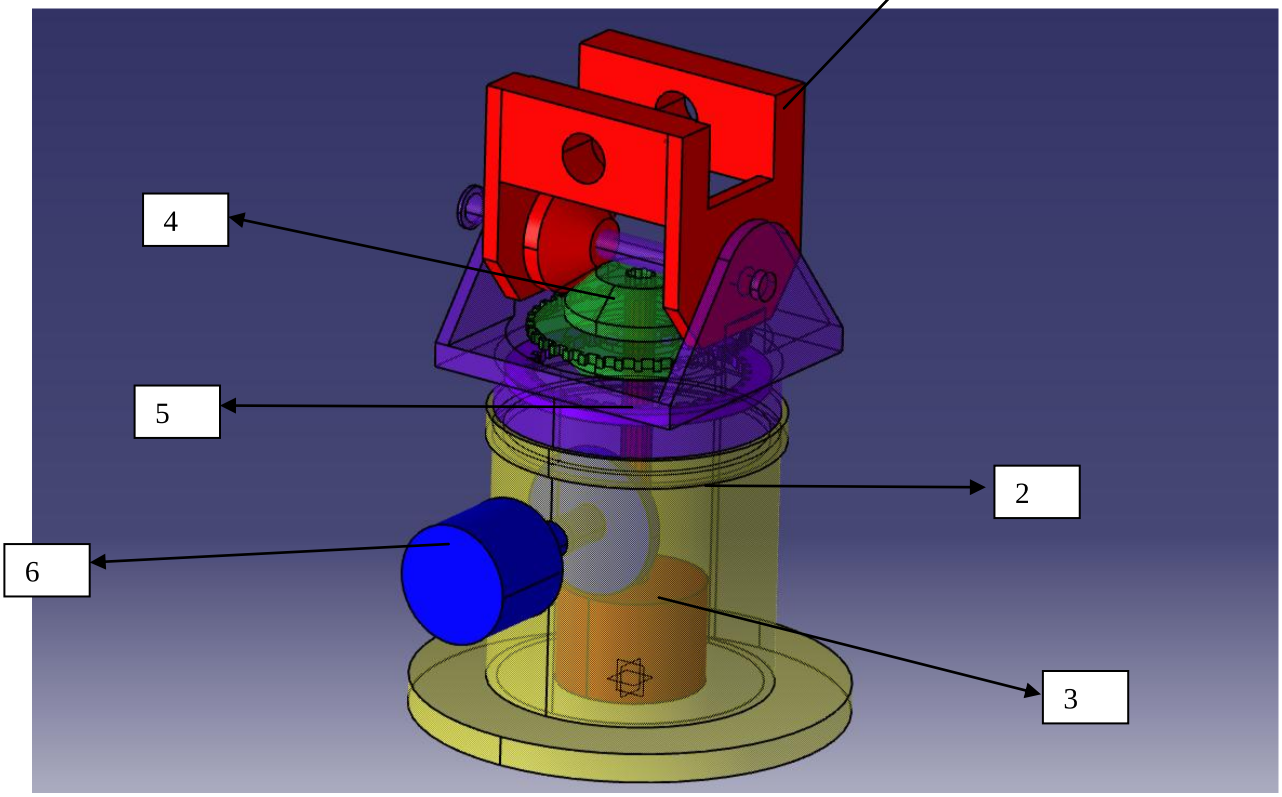

Fig 5 – Design that facilitate single actuated concentric driven robot wrist

3.2.1 Description of the design:

As can be seen Motor (3) is mounted inside the Box B (Fig-1) shown in Fig 2.To provide yaw motion Gear assembly (4) can be engaged with the spur gear arrangement inside the Box B. The shaft (6) is attached with the arm & its motion can be activated when gear assembly engages with the bevel gear arrangement as shown above. The motion achieved with this arrangement is called pitch motion. To achieve roll motion, the gear arrangement engages with the body 1 shown above.

3.3 Disadvantage of the above model & Modified design

3.3.1 Disadvantages of the above model

The above model has severe disadvantage of switching between different motions by use of different sets of gear arrangements, which in real sense in not feasible, as there are minimal probability of engagement between different gears, while in motion.

3.3.2 Description of the proposed rough design

The design shown in below figures i.e. Fig 6, 7& 8 consists of three different cylinders placed in series & providing roll-pitch & yaw motion respectively. As can be seen in the figure Box 1 is imparted roll motion, when spur gear attached to the box 1 engages with the Input shaft. To provide pitch & yaw motion another shaft is driven by engaging magnetically with the Input shaft & this shaft is connected to the 3-way bevel gear that provides motion to the main shaft as shown in the figure using belt arrangement. To provide pitch & yaw motion, different cylinders attached to the housing mounted on Box-1 is activated using magnetic grippers & respective motion is imparted to them.

3.4 Rough Design of the modified model

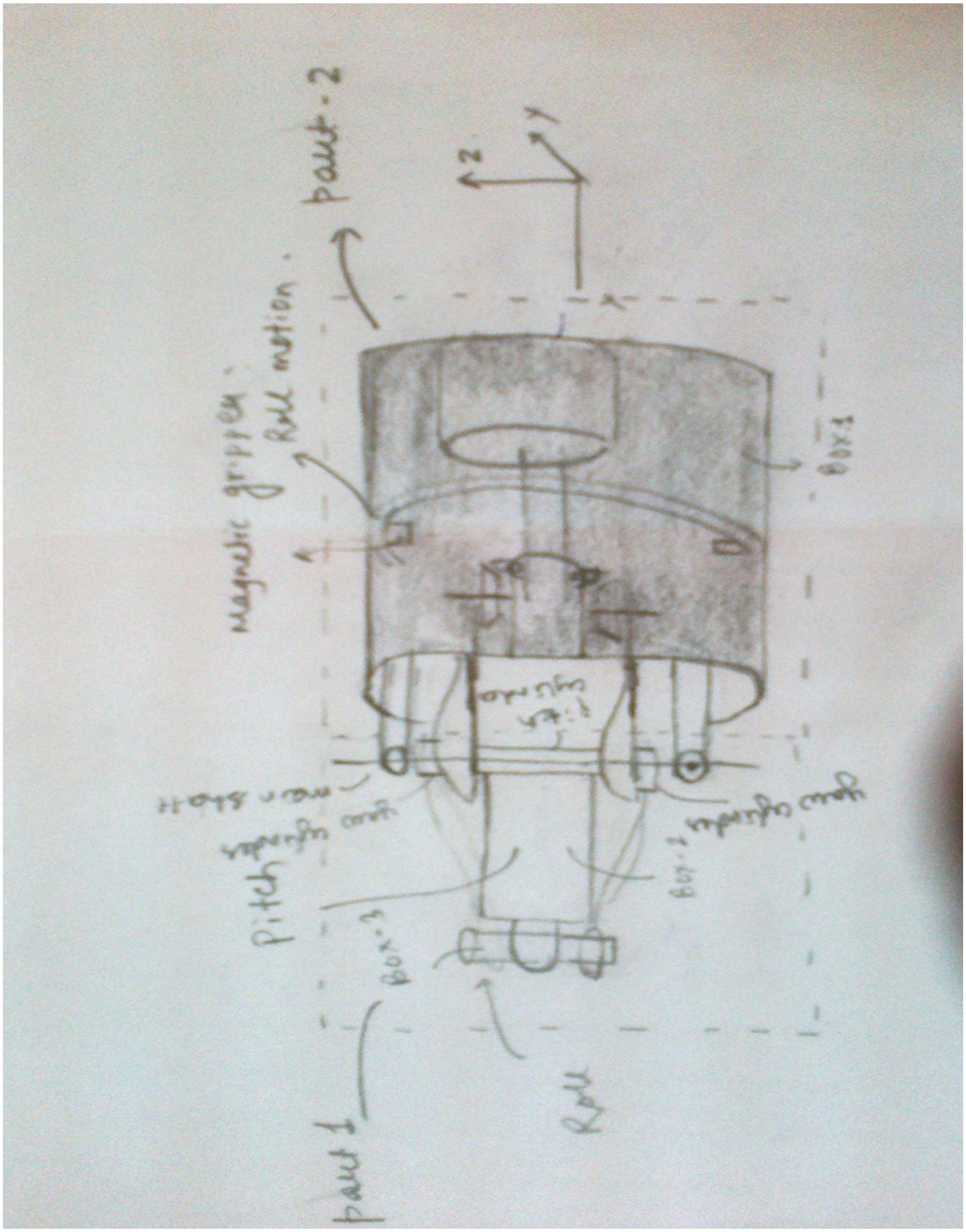

Fig-6-Showing Complete Model of Proposed design

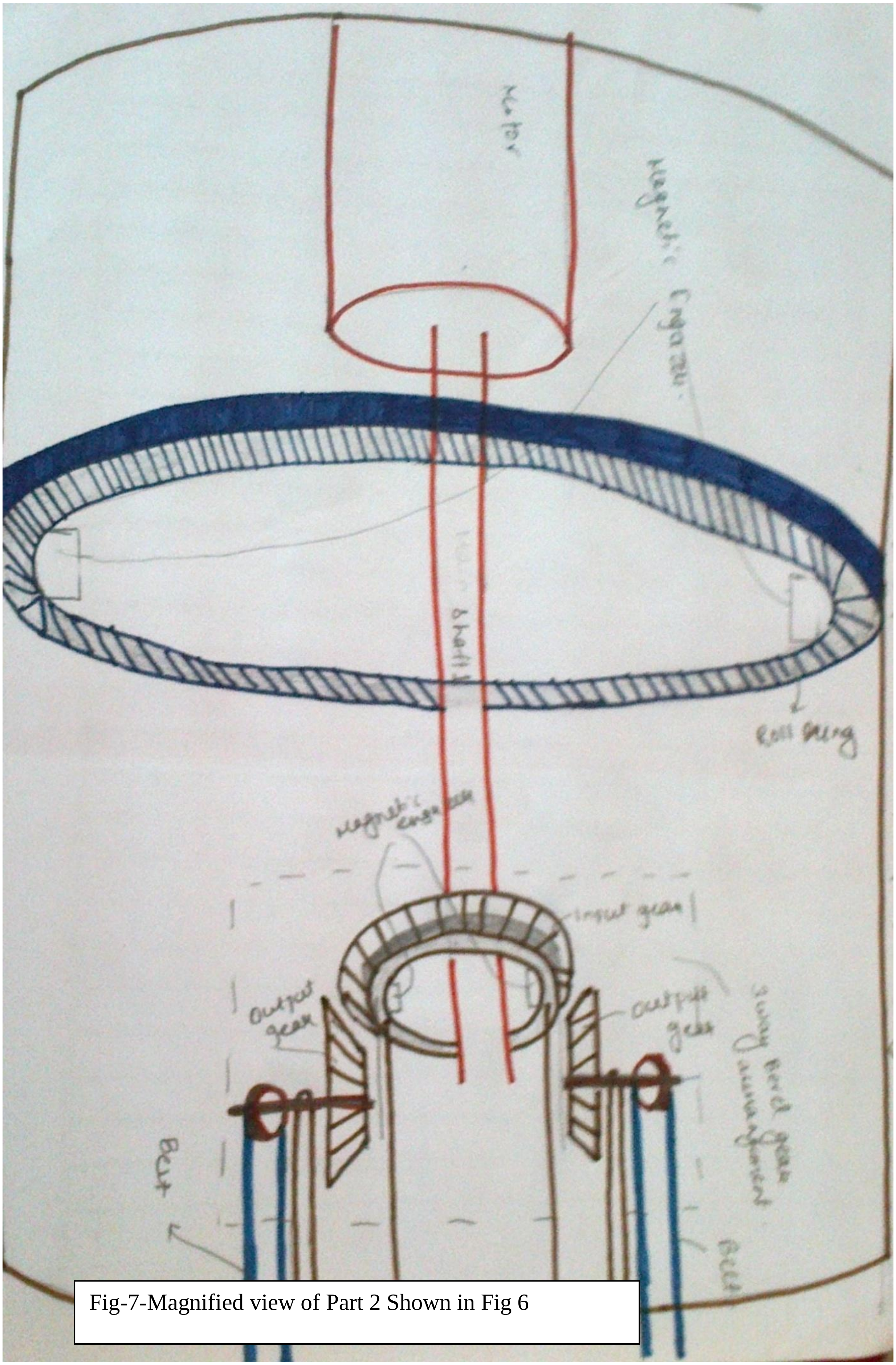

Fig-7-Magnified view of Part 2 Shown in Fig 6

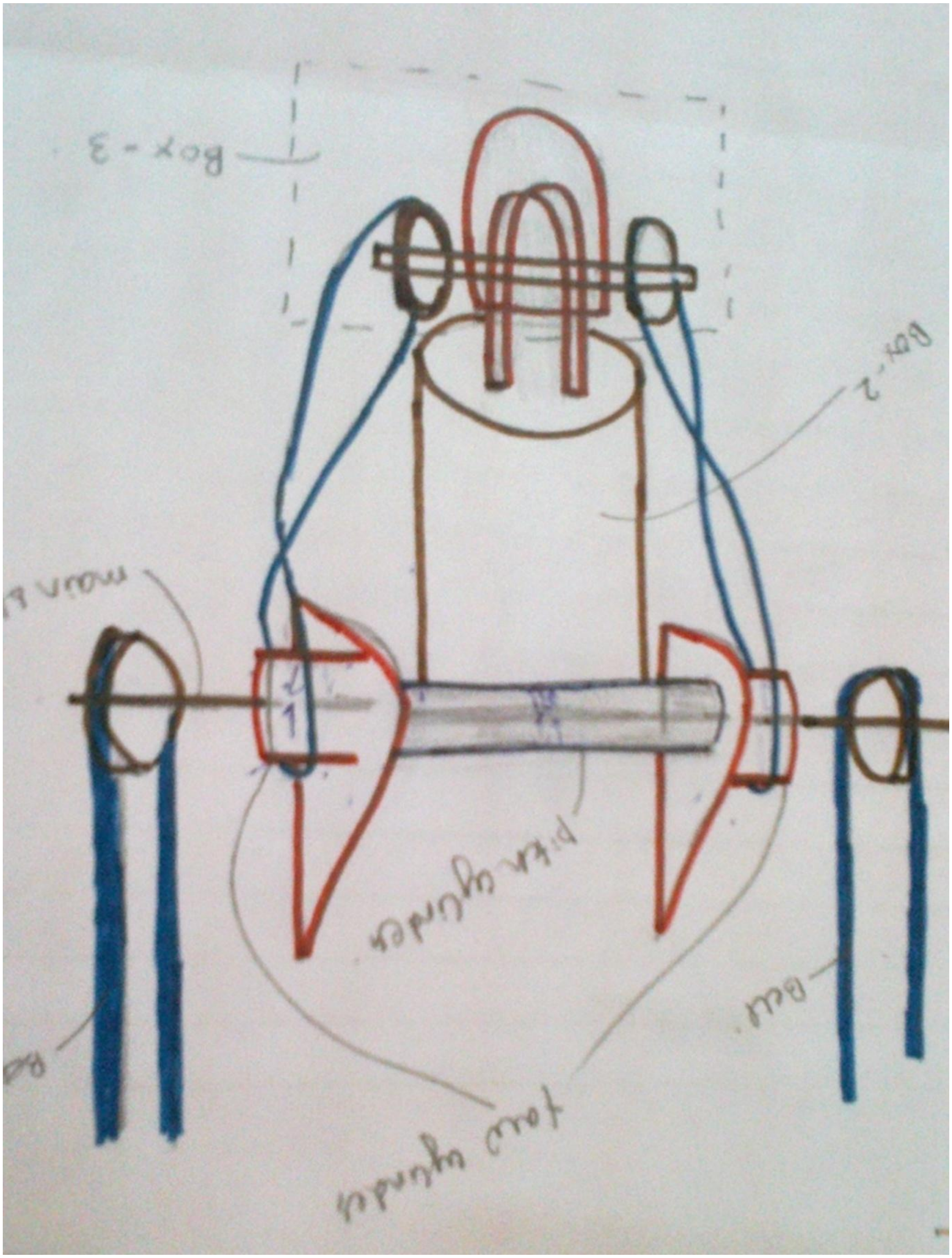

Fig-8- Magnified view of Part 1 Shown in Fig 6

3.4.1 Description of the Model shown in Fig 6, 7 & 8

As shown in Fig 6, & its magnified view in Fig 7&8 showing its detailed view by dividing the whole figure 6 into two parts as shown by dotted lines. To provide roll motion a magnetic engagement mechanism is applied with the roll ring &which rotates the box 1. To provide pitch & yaw motion MEM is turned on & it drives the shaft associated with 3-way Bevel gear set ,which has an I/P shaft & output shaft).Output shaft of 3-way bevel gear drives the shaft through belt arrangement made between output shaft & shaft. To provide pitch motion MEM is activated & for providing yaw motion, MEM is activated, which drives the worm set of gear arrangement & hence through belt arrangement, it drives the plate for yaw motion.

3.5 2D Cad model of the above proposed design as shown in fig 6, 7 & 8.

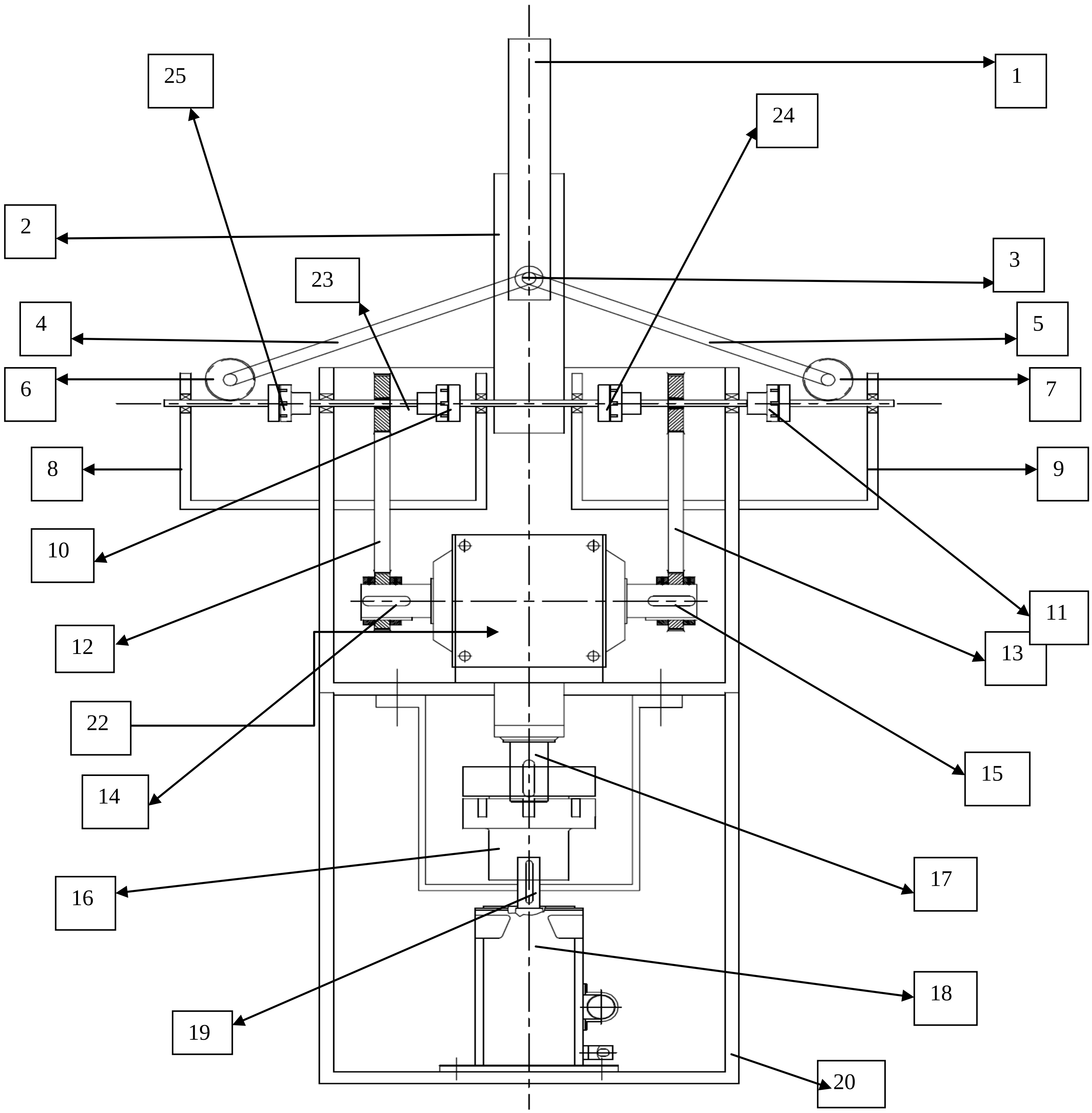

Fig 9- 2-D model representing the design to be manufactured

3.6 Description of the above 2D model as shown in Fig 9

Motor (18) Drives the I/P shaft(19) ,in order to provide for roll motion EM Clutch (16) is deactivated & I/P Shaft rotates the whole cylindrical body(20).To provide pitch & yaw motion EM Clutch (16) is turned on & it drives the shaft associated with 3-way Bevel gear set (22),which has an I/P shaft (17) & output shaft (14 & 15).Output shaft of 3-way bevel gear drives the shaft(23) through belt arrangement made between output shaft(14,15) & shaft(23).To provide pitch motion EM Clutch(24,10) is activated & for providing Roll motion ,EM Clutch(11,25) is activated ,which drives the worm set(6,7) of gear arrangement & hence through belt arrangement ,it drives the plate(1) a yaw motion. In the above design support structures (8, 9) to support EM Clutches & shafts associated with pitch & yaw motion.

3.7 Disadvantages associated with the Model shown in Fig 9

1. We need to provide two EM Clutches within cylinder (20) because roll motion would always be associated with the motion.
2. Since plate(1) that has yaw motion associated with it moves with cylinder (2) that provides pitch motion, hence angle between belt worm gear(6,7) that drives belt & plate(1) ,which is driven ,changes ,hence there are chances of belt coming out & whole system would malfunction.

Chapter 4

Final Design

4.1 Description of sub-assemblies for the final Product (wrist) design

4.1.1 Sub-Assembly Part 1

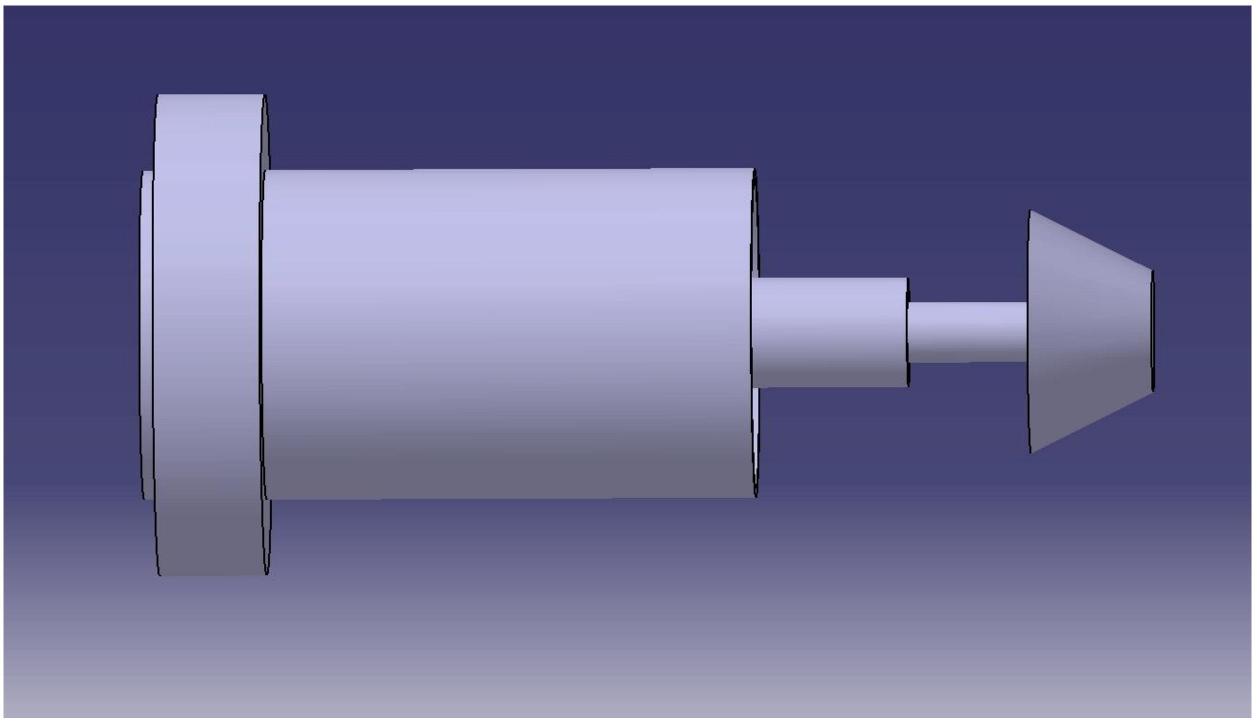

Fig 10- Figure of first sub assembly of the Product design

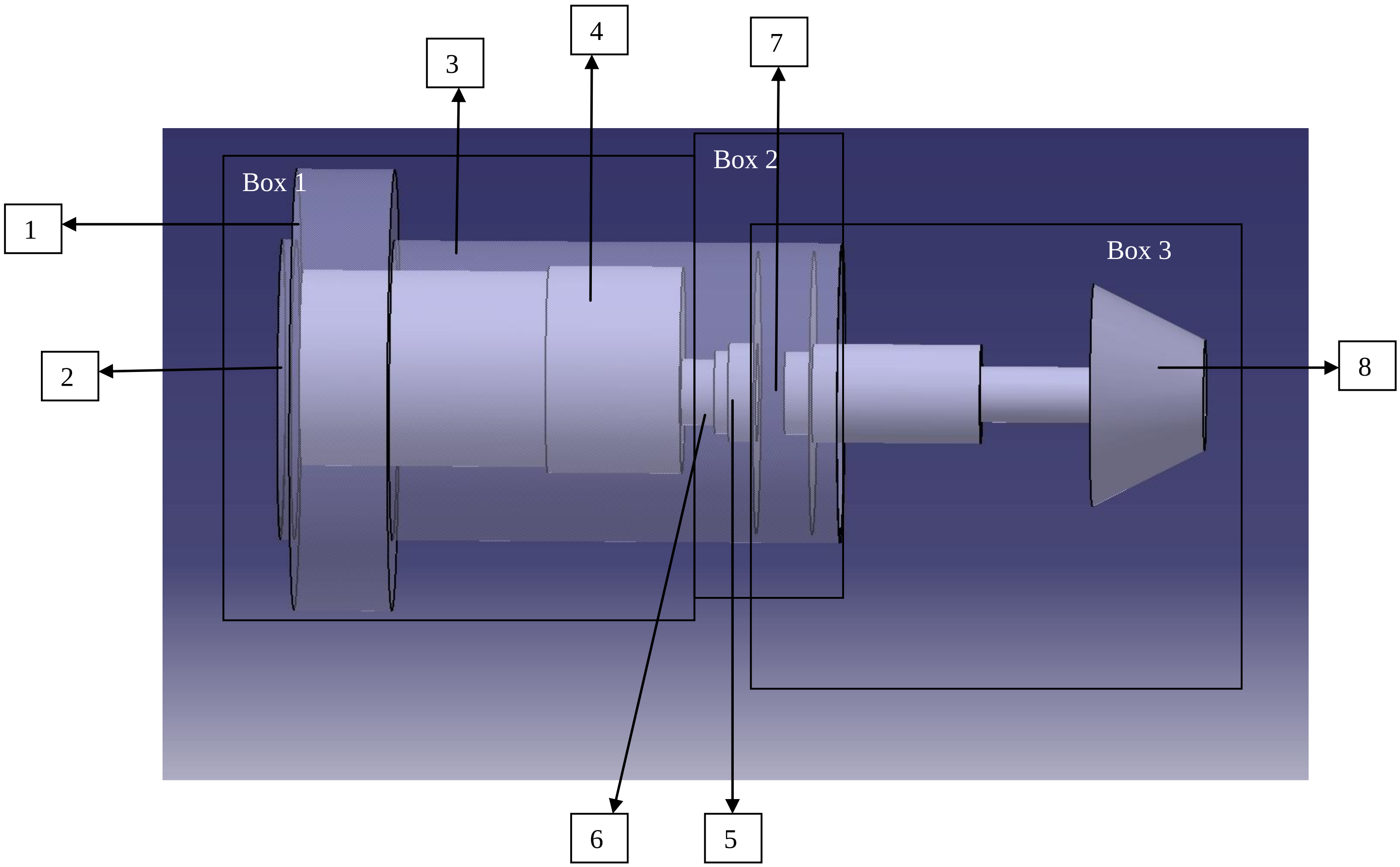

Fig 11: Inner view of the 1st Subassembly

Table 1 – Details of various parts shown in 1st Sub-Assembly

Part Number	Name of the part	Description of the part
1	Ball Bearing 1	This ball bearing is used to provide roll motion when sprag clutch (6) engages with driving shaft 5.
2	Clamper	This part is used to attach the whole assembly to the arm of manipulator.
3	Roll Cylinder	This cylinder is provided roll motion by activating RR clutch.
4	Motor	It is used to provide motion to the driving shaft
5	RR Clutch 1	This type of clutch has inner cylinder attached to the driving shaft & outside cylinder attached to driven cylinder (3).When in de-activated mode, it rotates with the driving shaft but doesn't provide motion to the driven cylinder but on activation later starts rotating with driven one.
6	Driving shaft	This shaft is used to transmit different motion to the wrist depending upon activation of various clutch attached with the mechanism. This shaft is activated by motor (4).
7	FSEM Clutch Gap 1	A gap is provided to attach FSEM Clutch to the driving shaft, hence transmitting pitch & yaw motion to the mechanism.
8	Bevel gear 1	This bevel gear is used to transmit motion to 2nd Sub assembly for providing yaw & pitch motion

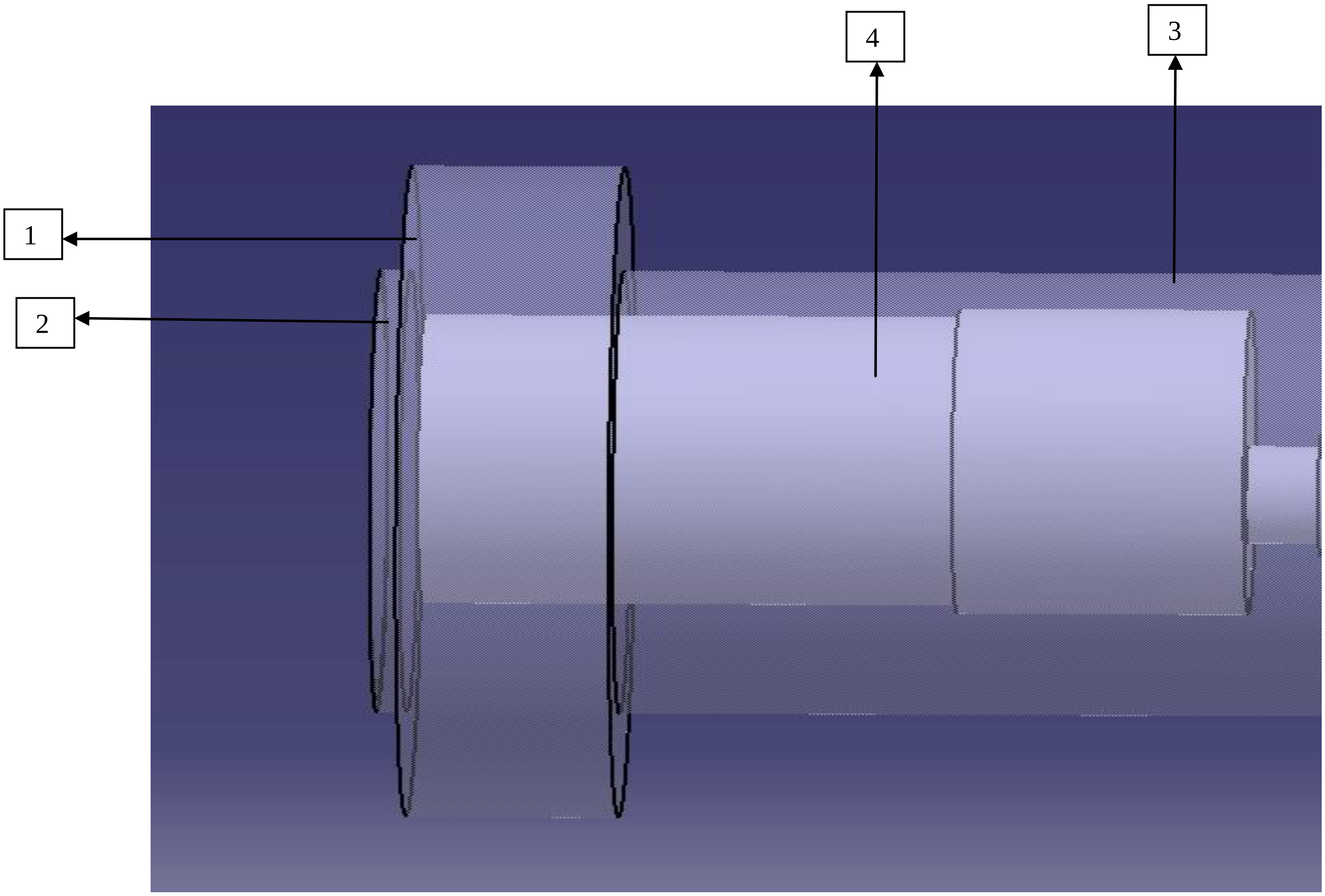

Fig 12: Magnified view of the box 1 shown in Fig 11

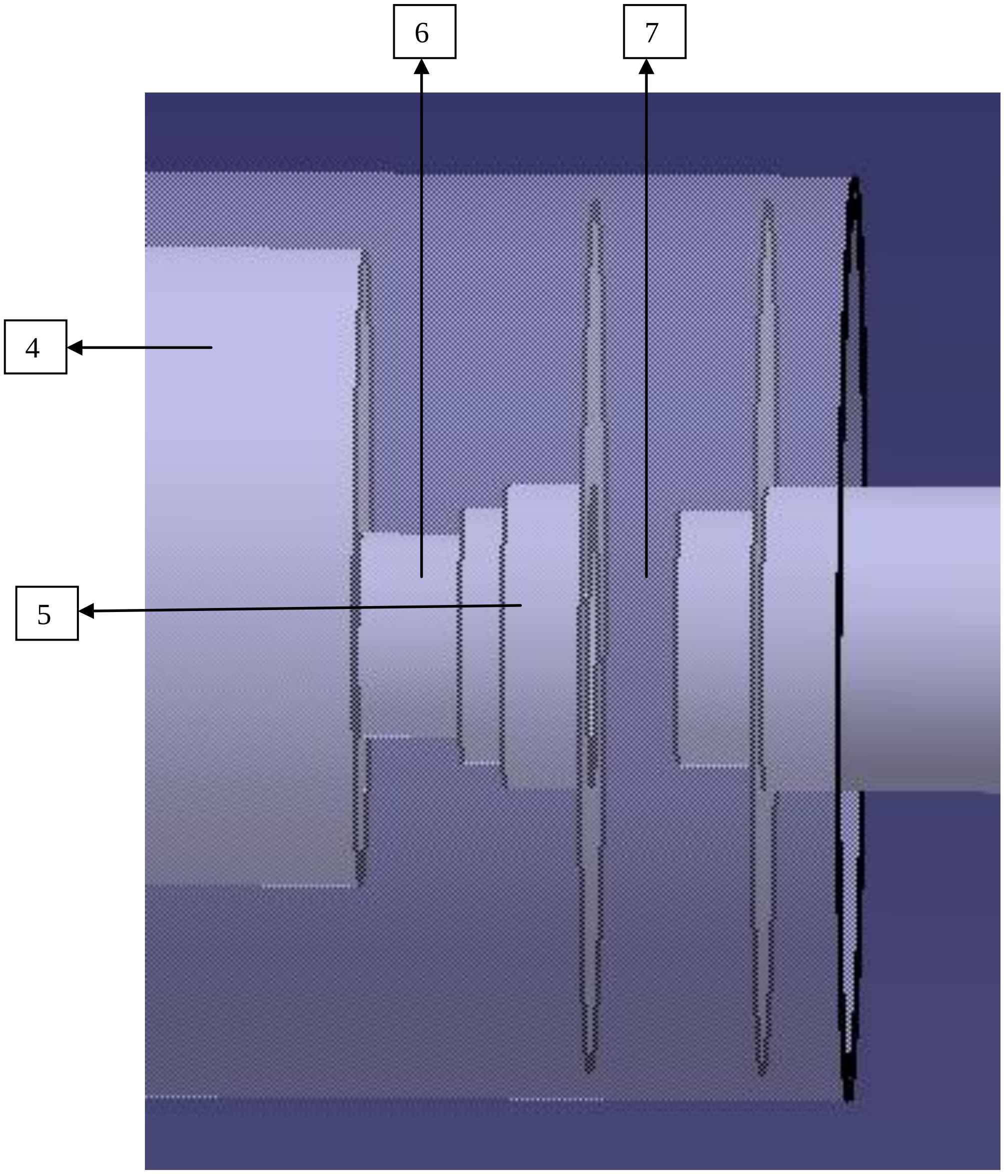

Fig 13: Magnified view of the box 2 shown in Fig 11

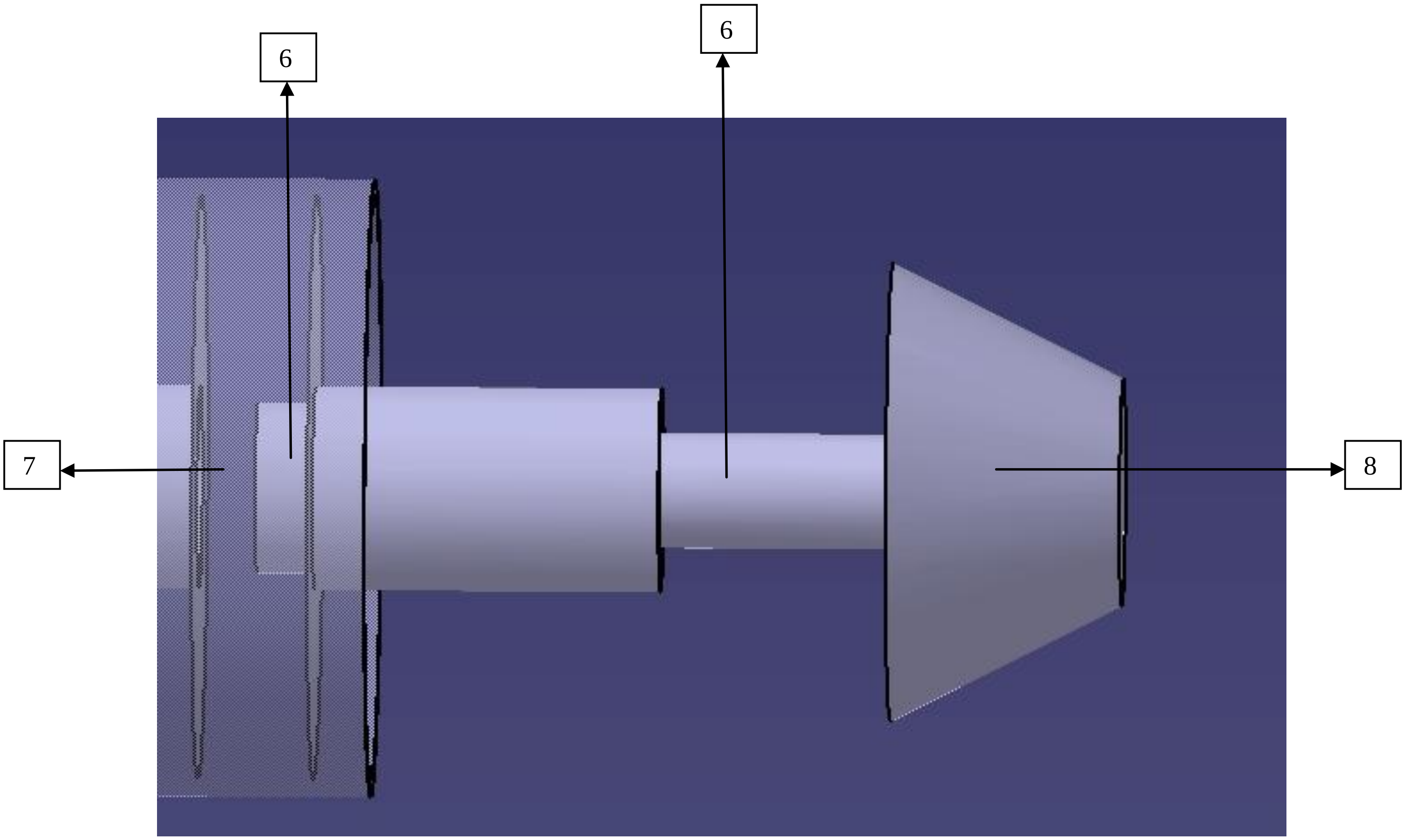

Fig 14- Magnified view of the box 3 shown in Fig 11

4.1.2 Description of the Sub assembly 1:-

As shown in Fig 10-14 with Fig 10 showing the first sub assembly, fig 11 showing labeled Sub assembly & Fig 12-14 representing the detailed view as shown in 3 boxes labeled in Fig 11.This sub assembly is responsible for providing roll motion & transferring rotation about motor shaft axis to the axis perpendicular to it.

4.1.3 Sub-Assembly Part 2

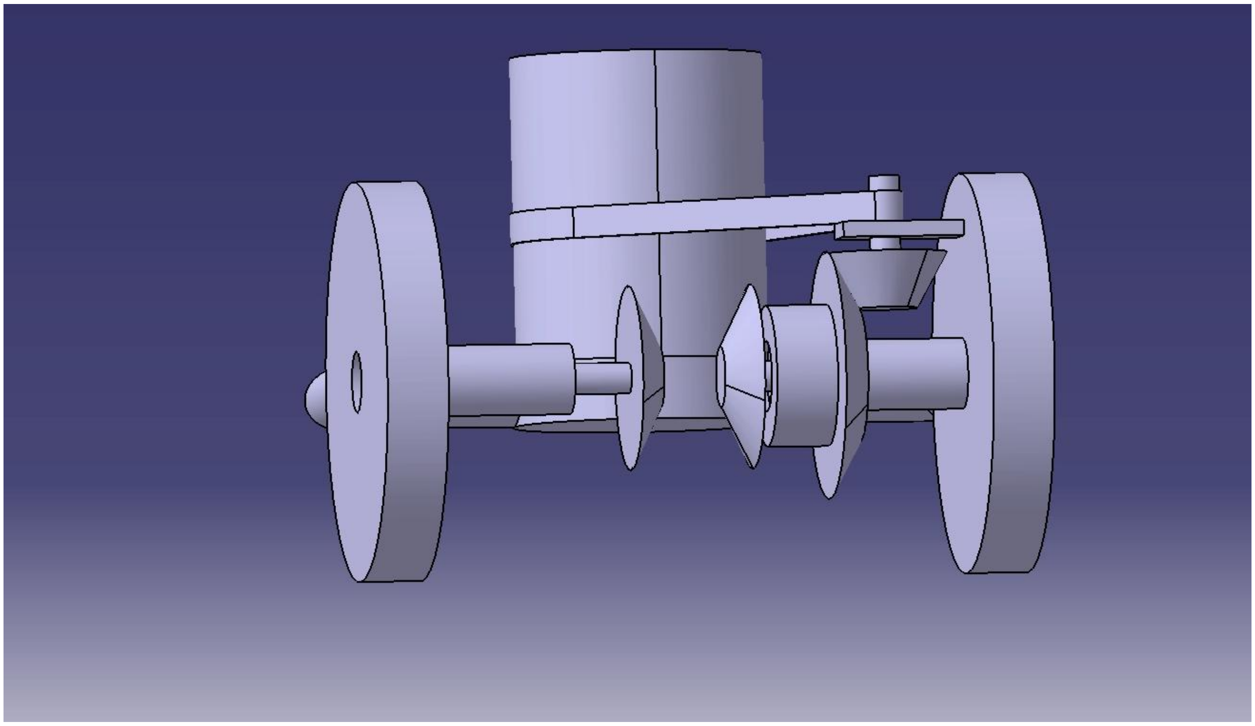

Fig 15 – Figure of 2nd Sub Assembly for Product Design

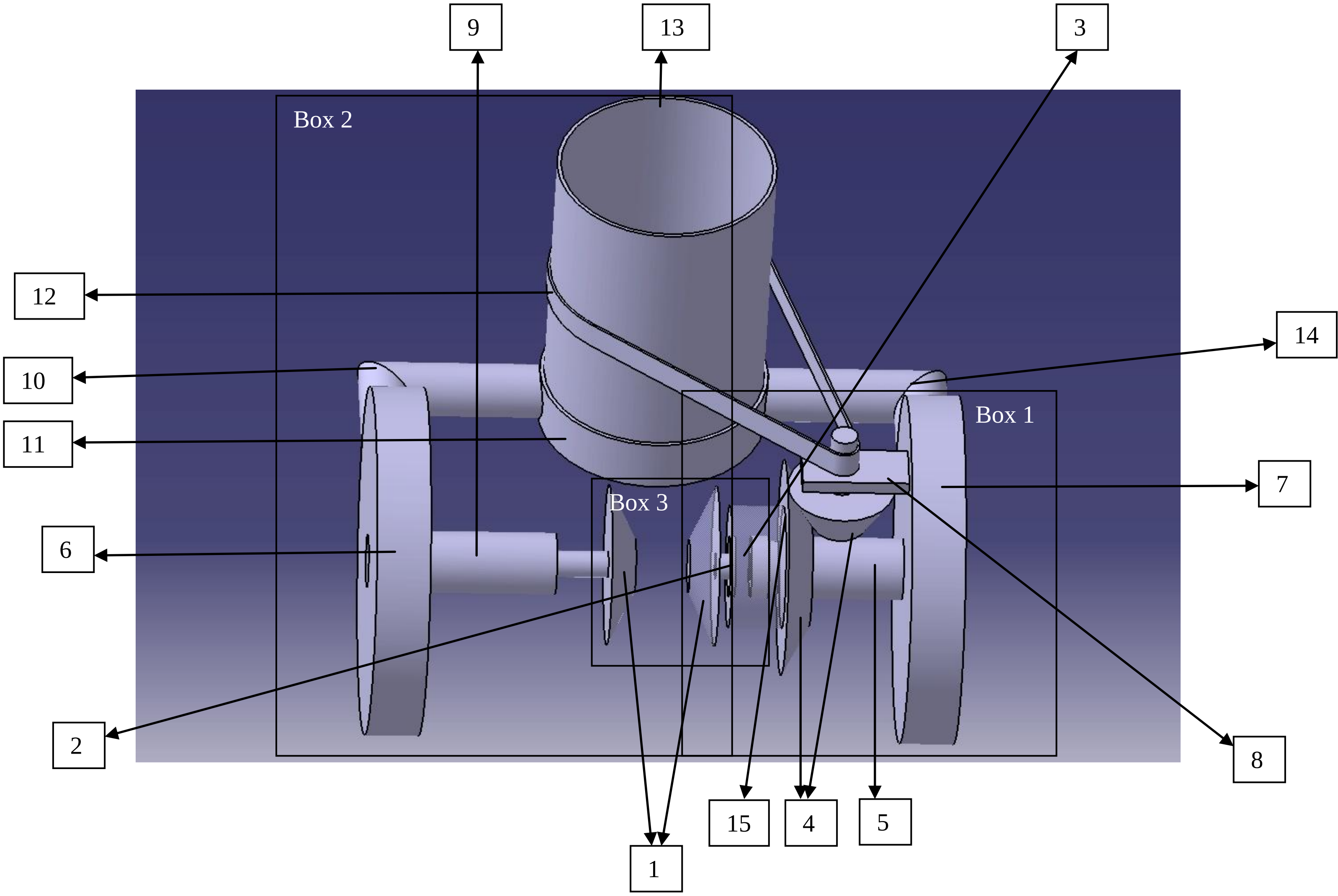

Fig 16 – 2nd Sub assembly design with some inner details

Table 2- Details of various parts shown in fig 16

Part Number	Name of Part	Description of part
1	Bevel Gear 2	This set of Bevel gear is engaged to the Bevel gear 1 & rotates as EM Clutch 1 is engaged as shown in Fig 11.
2	RR Clutch 2	This clutch is used to Transmit motion from BG2 to the pitch cylinders (6, 7).
3	FSEM Gap 3	EM clutch is to be installed in the gap shown above & due to this clutch engagement/disengagement yaw motion is transmitted to the yaw cylinder (13).
4	Bevel Set 1	This set of bevel gears is used to convert motion provided by BG2 arrangement to the yaw motion.
5	Pitch Shaft 1	This shaft transmits motion from RR clutch to the pitch cylinder.
6	Pitch Cylinder 1	This cylinder when provided motion by the pitch shaft, rotates to impart pitch motion.
7	Pitch Cylinder 2	This cylinder when provided motion by the pitch shaft, rotates to impart pitch motion.
8	Gear Holder	This holder is attached to the Pitch cylinder PC2 for holding the bevel gear & housing an FSEM Clutch to prevent yaw motion as pitch motion is transmitted.
9	Pitch Shaft 2	This shaft is used to transmit motion from BG2 to the Pitch cylinder.
10	Connecting rod 1	This rod is used to connect PC1 to the Yaw cylinder housing.
11	Yaw cylinder housing	This cylinder is used to house yaw cylinder in which later rotates about a ball bearing mounted on it.
12	Belt	This connects Bevel set 1 to the yaw cylinder for transferring yaw motion obtained through Bevel set arrangement mounted on Pitch shaft 1 through ball bearing 2.
13	Yaw Cylinder	This cylinder is mounted on the outer diameter of Ball bearing fit on Yaw cylinder housing.
14	Connecting rod 2	This rod is used to connect PC2 to the Yaw cylinder housing.
15	Ball bearing 2	This ball bearing is mounted on the Pitch shaft 1 to transmit motion achieved through RR clutch engagement to the Bevel set 1 for transmitting Yaw motion.

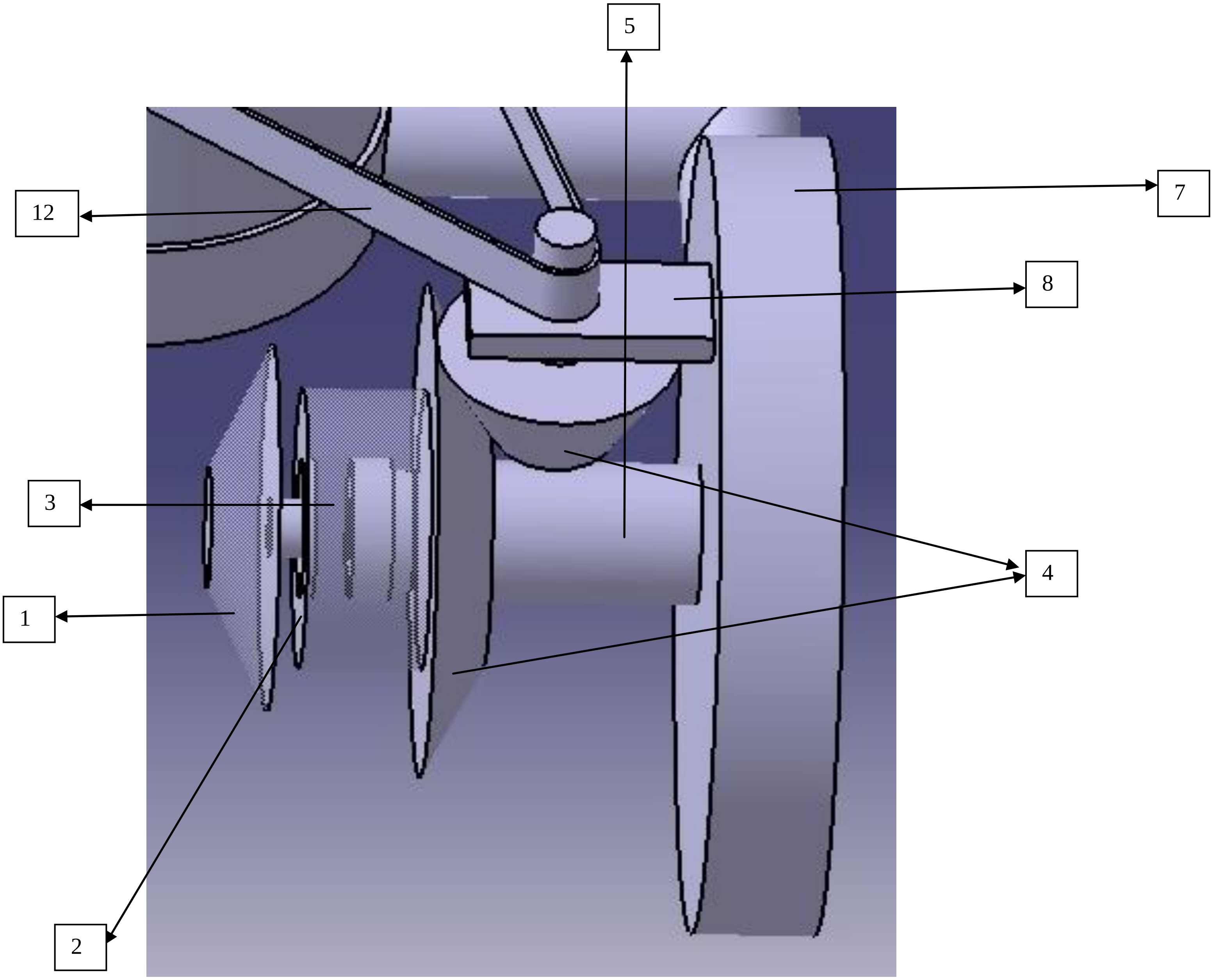

Fig 17 – Magnified view of Box 1 shown in Fig 16

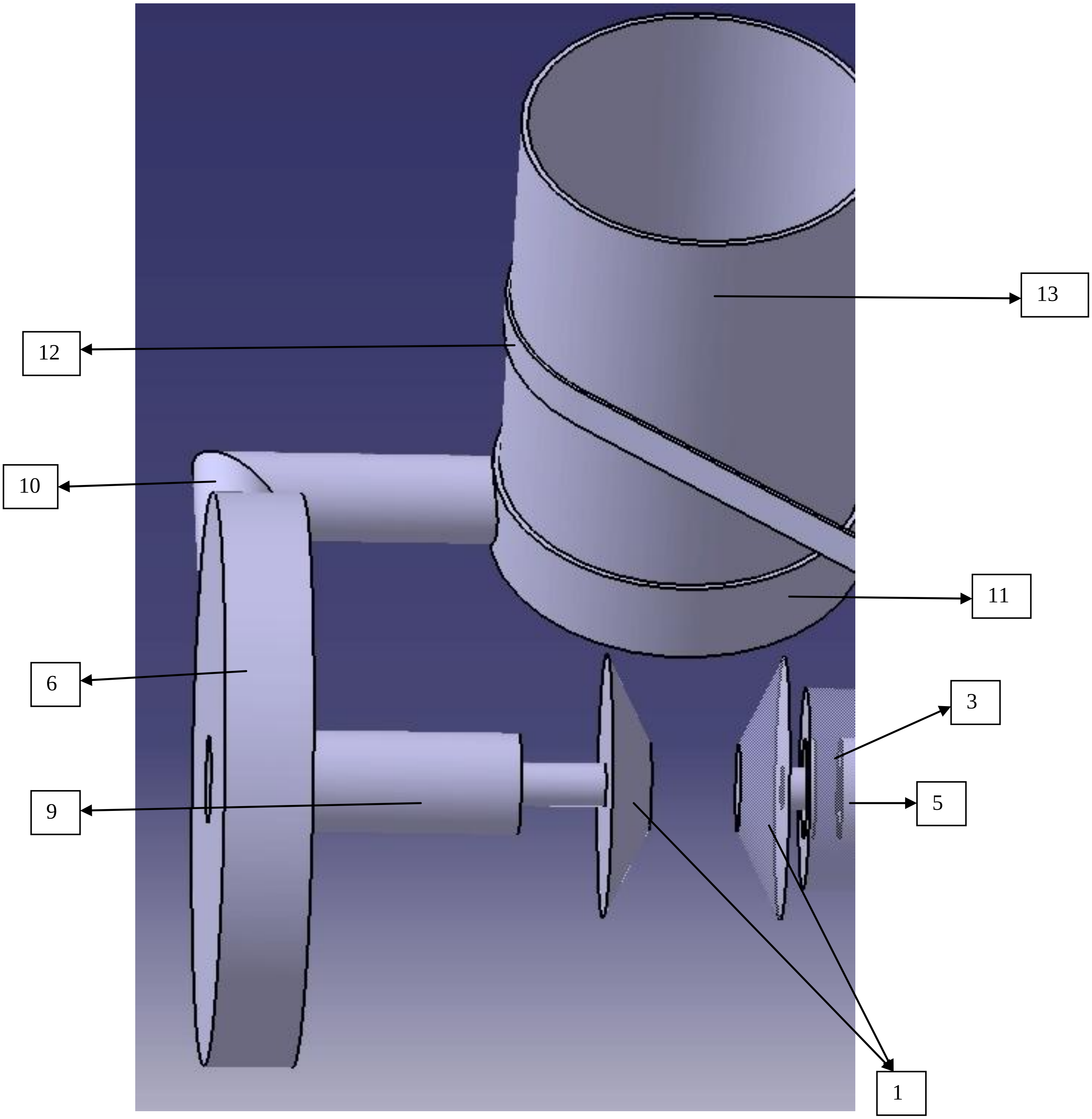

Fig 18- Magnified view of Box 2 Shown in Fig 16

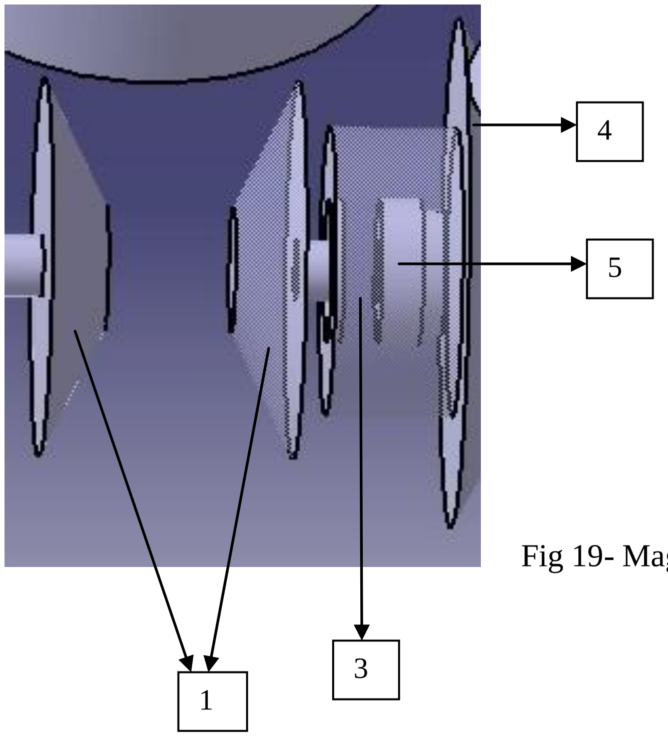

Fig 19- Magnified view of Box 3 shown in Fig 16

4.1.4 Description of sub assembly 2

Sub assembly 2 as shown by Fig 15-19 represents the sub assembly showing mechanism for providing yaw & pitch motion to the main wrist assembly. Fig 15 represents the complete view of the second sub assembly with Fig 16 representing the complete sub assembly with proper labeling & showing some inner details too. Fig 17-19 represents the details view of boxes shown in fig 16.

4.2 Assembled Product

An assembly of Sub-Assembled products 1&2 is shown in figure mentioned below.

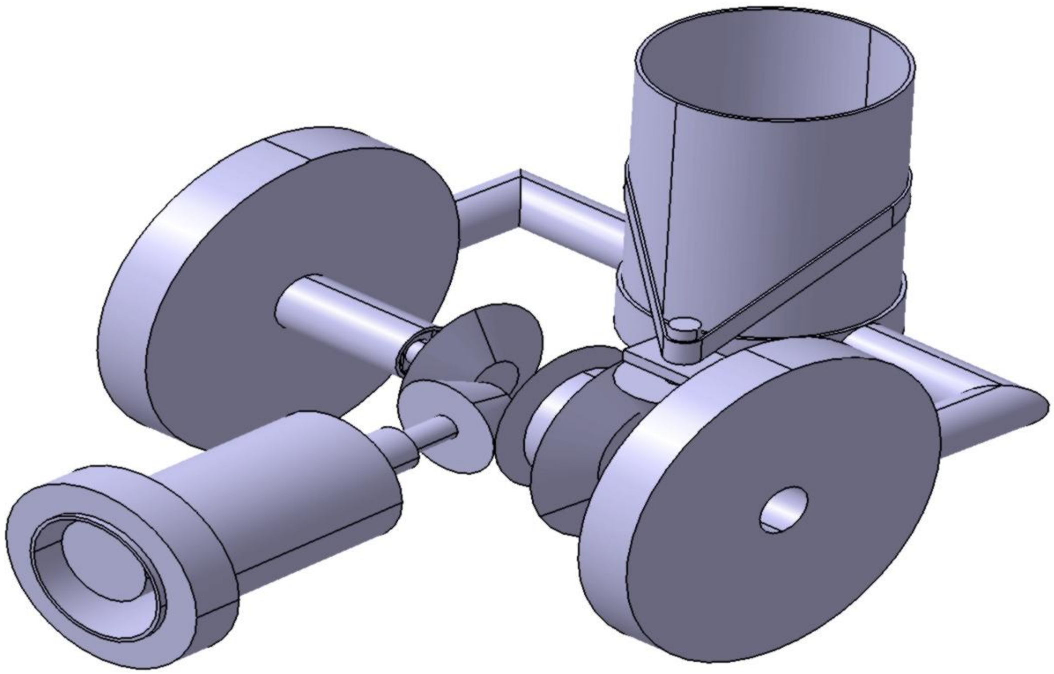

Fig 20 – Assembled view of the Parts shown in fig 15 & 10

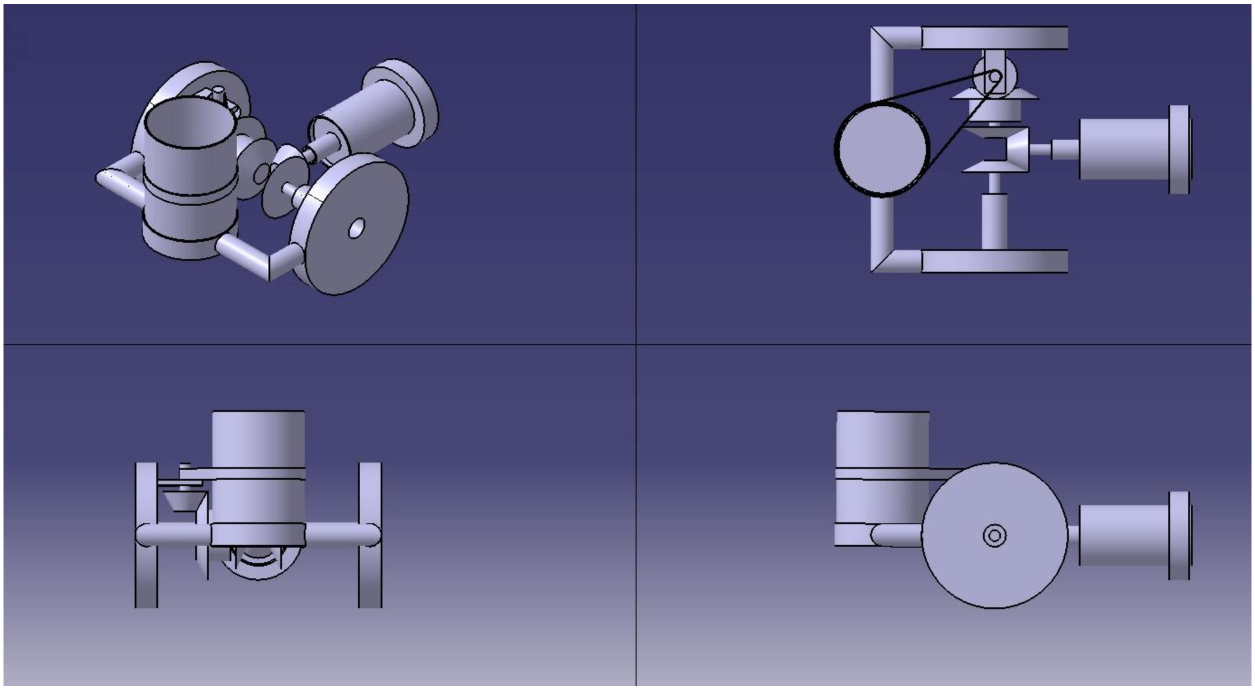

Fig 21 – Four isometric views of the assembled design

4.2.1 Description of the assembled design

The objective of Y-P-R motion using single motor as a actuator have been shown through assembled design in fig 20.As motor starts ,driving shaft attached with it starts rotating. For providing roll motion to the design, RR clutch1 attached with the driving shaft is activated, leaving all other clutches deactivated. As motion is transferred through RR clutch 1, roll cylinder attached to clutch starts rotating about clamper over ball bearing attached to the later. To provide Pitch & yaw motion, RR clutch 1 is deactivated & FSEM Clutch1 attached to the driving shaft is activated. Now as Bevel gear 1 attached to the bevel gear 2, so motion imparted to BG1 is Converted to a perpendicular motion through BG2 .Shaft attached to the BG2 rotates providing yaw motion by activating FSEM clutch 2 attached between Pitch shaft & BG2.To achieve yaw motion RR clutch attached to BG2 shaft is activated which drive the bevel set 1 ,and later transfers that motion to yaw cylinder through a belt arrangement attached to Bevel set 2.An

FSEM is also attached to the gear holder ,so that when pitch motion occurs ,bevel gear set doesn’t transfer that motion to the yaw cylinder. The bevel gear 1 & Bevel gear 2 can be combined together to form a 3 way bevel gear arrangement, which is readily available in market.

4.2.2 Description of RR (Roller ramp) clutch used in Product Design

Roller-ramp type clutches transmit torque through rollers that ride on the ramped surface of a hub, Figure 24.When the clutch is engaged, a roll cage positions the rolls at the top of the ramps and torque is transmitted from the continuously rotating .(3)

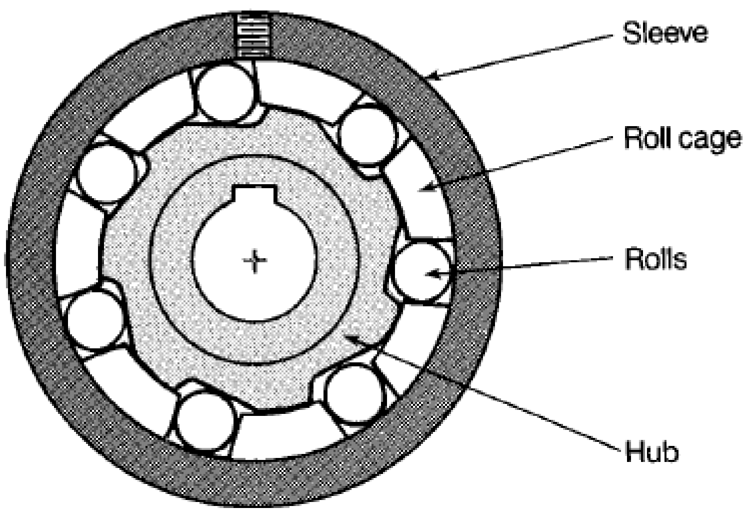

Fig 22 – Roller Ramp clutch (3)

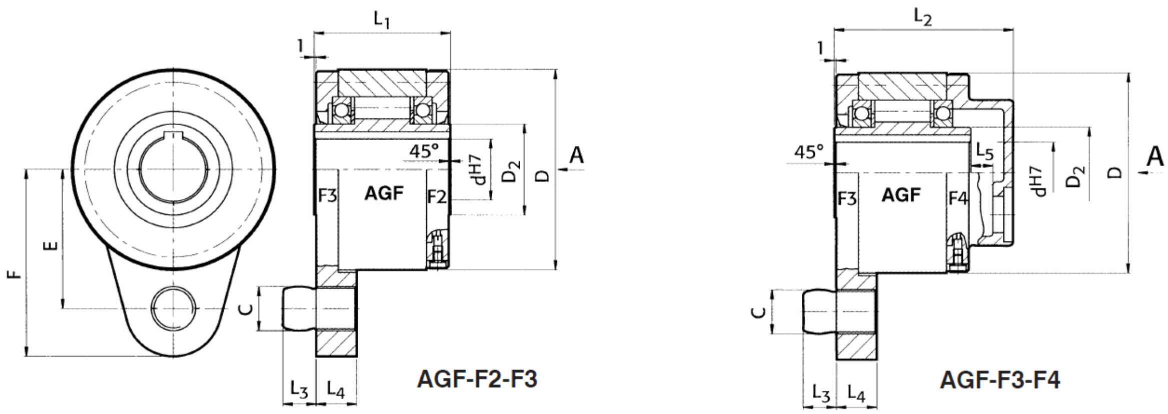

Fig 23- Cad Model of RR Clutch (4)

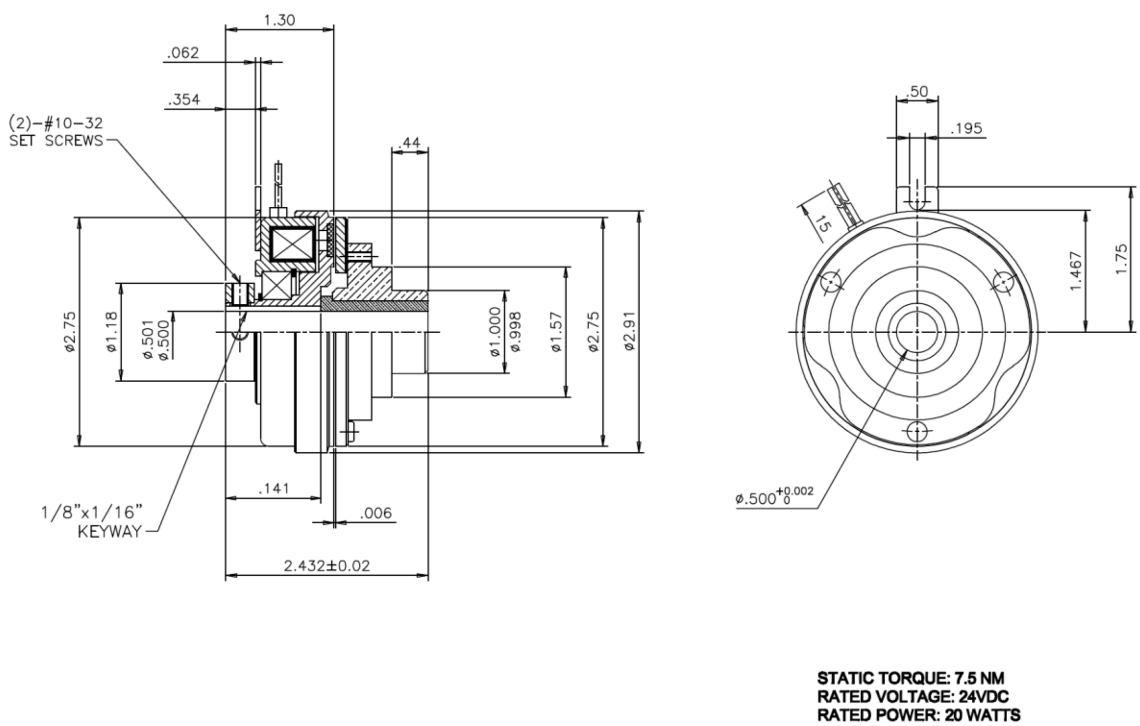

Fig 24: Cad model of Failsafe EM Clutch (5)

4.2.3 Description of the Fail safe Electromagnetic clutch

When the clutch is required to actuate, current flows through the electromagnet, which produces the magnetic field. The rotor portion of the clutch becomes magnetized & sets up a loop that attracts the armature. The armature is pulled against the rotor & frictional force is generated at the contact. Within a relatively short time, the load is accelerated to match the speed of rotor, there by engaging the armature & output hub of the clutch. In most cases rotor is constantly rotating with input all the time.

4.2.4 3 way series bevel gear arrangement – As shown in Fig 11, this type of arrangement

Consists of 2 sets of bevel gear, in which, when motion is provide to input shaft, it drives the output shaft perpendicular to the direction of I/p shaft.

4.3 Final Product (Design of Robot wrist)

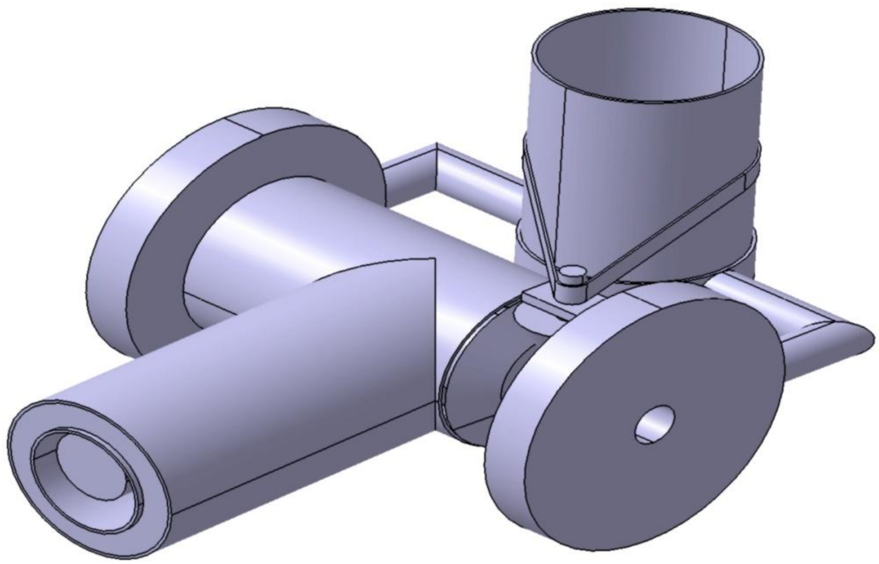

Fig 25- Robot wrist Design to be manufactured

Chapter 5

Wrist Design Specification

5.1 Table detailing specification of the wrist to be developed

Table 3:- Table detailing specification of the wrist to be manufactured

Sl No.	Specifications		Details
1	Configuration		3 axis concentric driven
2	Payload		Rated 5 kg /Maximum 9 Kg
3	Axis Rotation	Wrist Roll(J4)	±360
		Wrist Pitch(J5)	±90
		Wrist Yaw(J6)	±360
4	Horizontal Reach		65 mm
5	Vertical Reach		65 mm
6	Speed	J4	553 deg/sec
		J5	553 deg/sec
		J6	720 deg/sec
7	Cycle time (1 kg workload)		.37 sec
8	Allowable moment	J4	4.41 N*m
		J5	4.41 N*m
		J6	2.94 N*m
9	Moment of inertia	J4	.15 kg*m^2
		J5	.15 kg*m^2
		J6	.1 kg*m^2
10	Motor Rating		50 watt
11	Motor Type		DC Servomotor

Chapter 6

Results & Discussion

6.1Comparison of the new design with conventional wrists

As conventional design used to have as number of motors as the number of DOF for the product. As increase in the number of motors leads to more weight & cost & apart from that leads even increase in the number of gear arrangements in case of Remote actuation.

This design has the advantage over any existing design of wrist in many ways & it solves the purpose of remote actuation with single motor & even lesser number of gear arrangement in the gear train used.

6.1.1Advantages of this design over conventional design:-

1. Compact size, Light weight &Economical as it uses lesser number of gears & motors
2. Low manufacturing cost
3. Large workspace & can be easily adjusted by just adjusting the size of gears to be used.

6.1.2Disadvantages of this design over conventional design:-

1. Small error in any part of the design, leads to whole set-up becoming dysfunctional.
2. Low accuracy & repeatability.
3. Low mechanical stiffness.

6.2 Future Prospect of the project

Upon completion of the wrist design, details mentioned in the chapter 5 regarding components to be used to manufacturing can be employed to manufacture robot's wrist .Since data mentioned in the Table 3 is for a set of given capacity but this design can be extended to any payload but user needs to change the other data like motor rating, moments etc depending upon his requirements of load to be carried. This project can be basically helpful for surgical & nuclear application as most of its electric operated parts lies outside the wrist & involve even fewer gear trains than conventional robot wrists.

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