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Design and Development of Universal Adapter Plate for KUKA KR C4 Industrial Robot

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***Abstract*: A robot is generally used for pick and place operation of a component from one position of a machine area to the next. Generally, only one gripper is attached to a robotic arm for the pick and place operation and at times when more than one component is present, it becomes challenging to incorporate another robot for the pick and place of the second component. Hence this project aims at designing an adapter system for mounting two grippers together onto the end plate of a robot So that one robot can pick more than one different component by using the required gripper. Often the plastic parts which are to be picked might not be aligned properly with the fixture and hence could be hard for the pre-programmed robot to pick such parts. Camera setup could solve this problem by sending the coordinate values of the parts orientation to the robot control system and the robot aligning its gripping in the correct order as to grasp the part correctly. Alternate way to solve this problem considering cost as a major factor, misalignment compensation mechanism was designed which gives a free rotary motion to the gripper when required during picking operation and locks the rotation when the rotation degree of freedom is not required. Using the CAD model prototyping was done by using 3D printing technology and all the parts have been 3D printed to understand the design better with a real-world model.**

***Keywords*: Robot, Two finger and three finger gripper, Adapter system, Solid works 2018, Degree of freedom.**

1. Introduction

The term Robot comes from the Slavic word robot, meaning hard work. According to the official definition of an industrial robot. “A Robot is a freely programmable, program-controlled handling device.” The robot system thus also includes the controller and the operator control device, together with the connecting cables and software. Fundamentally, a robot is normally an electro-mechanical machine which is guided by the means of PC and electronic programming. The PC which is connected to the robot is programmed to control the motors on the robot joints in a way so that it can perform different tasks.

2. About KUKA KR C4

KUKA is a German manufacturer of industrial robots and solutions for factory automation.

The company was founded in 1898 in Augsburg, Germany, by Johann Josef Keller and Jacob Knappich. The acetylene factory Augsburg was founded in 1898 by Johann Josef Keller and Jacob Knappich for the production of low-cost domestic and municipal lighting, household appliances and automobile headlights. In 1905, the production was extended to the innovative autonomous welding equipment. After the First World War, Keller and Knappich resumed production of safety-, manual- and power-winches and began the manufacturing of large containers. As a result, the Bayerische Kesselwagen GmbH was formed in 1922. The new company was responsible for the development and production of superstructures for municipal vehicles (street cleaning machines, sewage trucks, garbage trucks). In 1927, this business division presented the first large garbage truck. The name KUKA came into being in the same year through the company’s name at that time “Keller und Knappich Augsburg”. Keller & Knappich GmbH merged with part of Industrie-Werke Karlsruhe AG to become Industrie-Werke Karlsruhe Augsburg Aktiengesellschaft, eventually KUKA (Keller und Knappich Augsburg) for short.

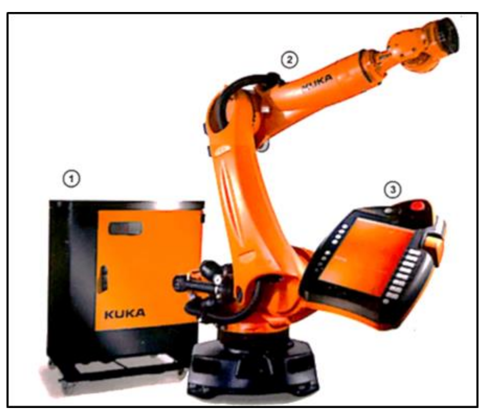

Fig. 1.

The above figure is the pictorial representation of the Industrial Robot by KUKA.

It includes:

1. Controller ((V)KR C4 control cabinet
2. Manipulator (robot arm)
3. Teach pendant (KUKA smart PAD)

Everything outside the system limits of the industrial robot is preferred to as the periphery, which includes:

- Tooling (end effector/tool)
- Safety equipment
- Conveyor belts
- Sensors
- Machines

The manipulator is the actual robot arm. It consists of number of moving links (axes) that are linked together to form a kinematic chain.

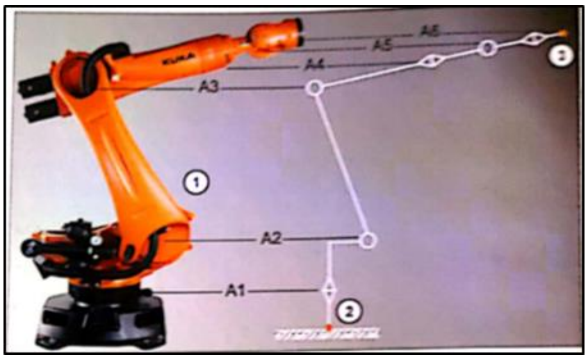

Fig. 2.

Manipulator consists of following parts:

- Manipulator (robot arm)
- Start of the kinematic chain: base of the robot.
- Free end of the kinematic chain: flange

The individual axes are moved by means of targeted actuation of servo motors. These are linked to the individual components of the manipulator via reduction gears.

3. Literature Survey

The paper Design of Three Fingered Robot-Gripper Mechanism by Krishna Raju A, Ram Kumar tells us regarding designing functional fingers of robots as it is one of the most complex and sensitive criteria in robotics. The current iterative and time-consuming procedure of designing fingers cannot fulfill the demands of agile manufacturing. Therefore, finger design automation plays a significant role in the competitiveness of the robotic automation in the agile market. Designing gripper fingers properly can increase the work cell throughput, overcome robot inaccuracy and enhance overall system performance.

The paper Design and fabrication of three finger adaptive gripper by S. Kaviyarasan and I Infant Mary Priya describes the capabilities of the interface, the practical realization within the LWR control architecture and first applications of the interface The FRI gives access to an industrial-strength controller at very high control rates up to 1 kHz from any client PC. The FRI is based on the KUKA Robot Controller KRC2

The paper titled Design of a magneto rheological robot gripper for handling of delicate food products with varying shapes by A Pettersson S Davis gives us idea regarding A novel robot gripper that utilizes the effects of a magneto rheological (MR) fluid is described and evaluated. This paper also presents data regarding the forces exerted on products during gripping as well as data on maximum payloads and graspable product shapes.

4. Concept Generation

This chapter deals with the process followed in brain storming different possible design solutions to our problem. We designed 3 different models as shown below and they were given rating on the scale of 0-10 with 0 being the list and 10 being the highest taking different parameters into account.

A. Model 1

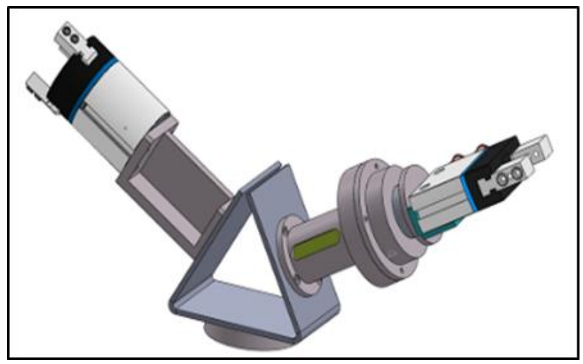
Fig. 3.

This is the first model in which the universal block was made of using a sheet metal which was of 5 mm thickness. The material used was Aluminium.

Pros:

- Ease of manufacturing
- Low cost
- Simpler design

Cons:

- Less accurate
- Less precision
- Failed in with standing high loads

B. Model 2

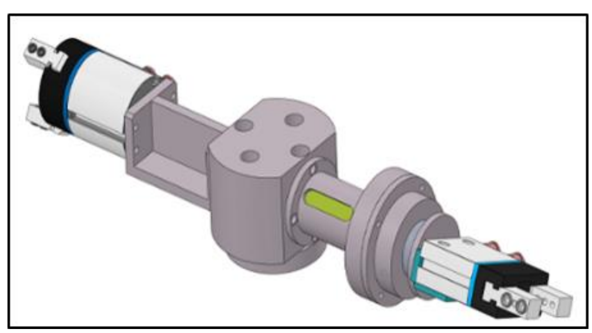
Fig. 4.

Considering the different modes in which the Model 1 failed, we designed the second model in which the sheet metal was replaced with the solid Aluminium block and both the fingers were made 180 degrees apart.

Pros:

- It had longer reach
- Larger work envelope
- Can handle heavier loads than Model 1

Cons:

- Chances of damage to other parts of robot while the operation being performed was high
- No ease of operation
- Machining was difficult

C. Model 3

Fig. 5.

In this model we tried to overcome all the disadvantages which were obtained in the earlier two models.

Since the use of solid Aluminium block gave us better result same was used here. The problem that was faced by making the grippers which were 180 degrees apart was overcome here by reducing the angle to 90 degrees between two grippers.

Pros:

- Increased precision, accuracy
- Risk of accidents was reduced

Cons:

- Complex design
- Modern methods of manufacturing required

D. Rating Table

Validation points	Model 1	Model 2	Model 3
Design complexity	5	5	6
Machinability	8	6	4
Accuracy	6	8	8
Ability to withstand heavy loads	3	8	8
Ease of operations	4	3	8
Aesthetics	4	5	7

By considering the above ratings, we came to the conclusion that Model 3 was well suited for our application and the design was finalized.

5. Design of Misalignment Compensation Mechanism and Multiple Gripper Holder

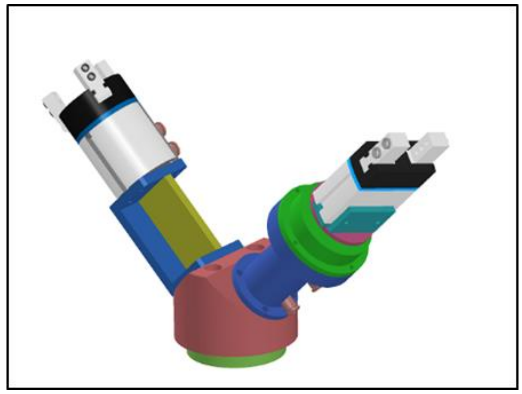

Fig. 6. Robot gripper

Serial No.	Assembly Name
1	Adapter Assembly
2	Three Finger Gripper Assembly
3	Misalignment Compensation Assembly

Adapter assembly:

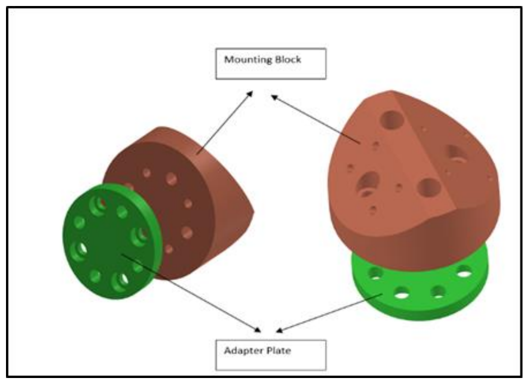

Fig. 7.

Four M6 bolts are used to attach the adapter plate to the mounting block and the adapter assembly to the robot end plate each.

As per the data from metric bolts website the proof load and clamp load permissible for M6 bolt Proof Load = 4520

The clamp load permissible in the bolt is 75% of proof load

= 0.75*4520

= 3390 N

(Proof Load is the maximum tensile load in a bolt which would not result in plastic deformation)

As the loads acted on the Adapter Assembly is not beyond a certain range, so the clamping force chosen is 1000 N on each bolts. The same amount of pre-tension is applied to the bolts joining the assembly to the robotic arm as well as for mounting adapter plate to the mounting block.

The Three finger and misalignment correction assemblies create a cantilever type of load on the mounting assembly and to simplify the meshing operation, the assemblies were replaced with blocks and their weight forces were acted on the blocks at the exact point of center of mass of the two assemblies,

- Weight of Misalignment mechanism assembly weight= 600 g
- Weight with component in gripper = 600gm + 50gm = 0.650 kg
- Centre of mass load = 0.650*9.81 = 6.375 N
- Weight of three finger gripper assembly = 400 gm
- Weight with component in gripper = 400+ 50= 0.450 kg
- Centre of mass load = 0.450*9.81 = 4.415 N

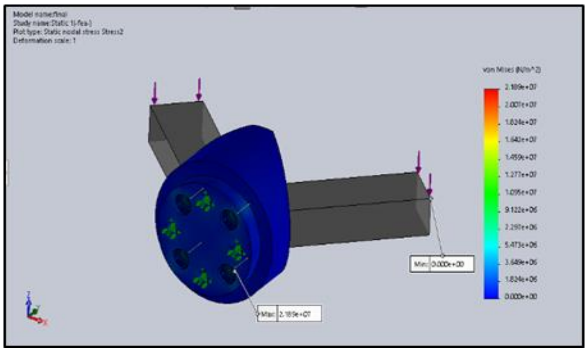

Fig. 8. Maximum and Minimum value of stress in the assembly

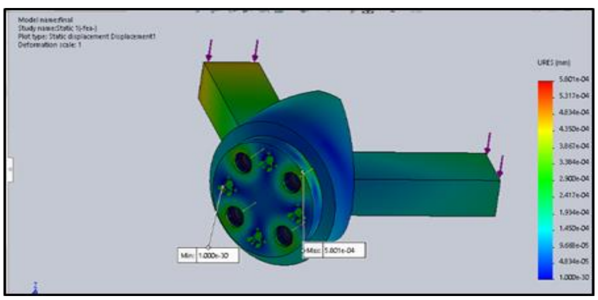

Fig. 9. Deformation data under the loads

A. Three finger gripper assembly

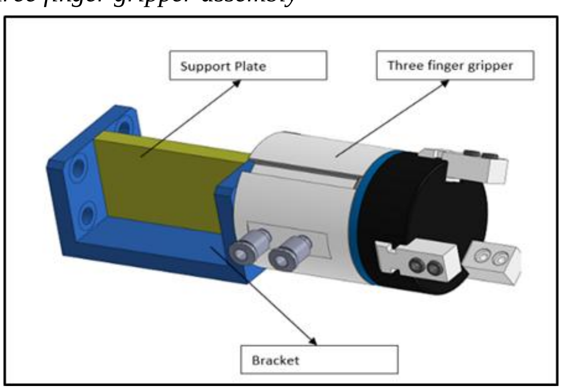

Fig. 10.

The support plate is directly mounted on one end of the mounting block using 4 M5 bolts.

The gripper chosen is the Festo 32 mm diameter compact gripper having the total gripping force at 6 bars as 405 N. The Standard values of the permissible torque and forces on the gripper jaws are given in the datasheet of the gripper and must be verified with the component chosen. The gripper is a double acting cylinder. The critical attachments here are the mounting of the support plate and gripper to the bracket.

The Support plate is attached to the bracket using two M4 bolts on each side on the plate, in total four M4 bolts are used.

The Proof Load of a M4 bolt = 1980 N

The maximum clamping force applied on bolt is = 0.75*1980 = 1485 N

As the load due to the gripper is not beyond a basic value, hence the pre-tension force applied on each bolt is 100 N, and this value was used to perform the analysis. The gripper is attached to the bracket using four M3 bolts and the pre-tension in the bolts applied is 80 N.

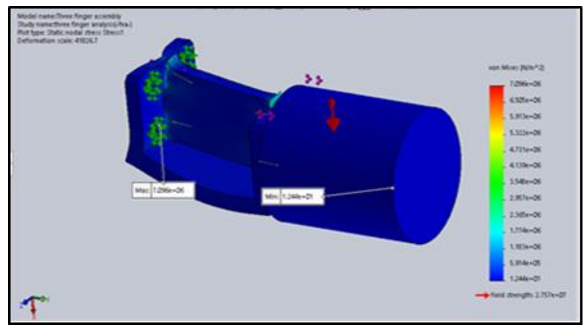

Fig. 11. Maximum and Minimum value of stress

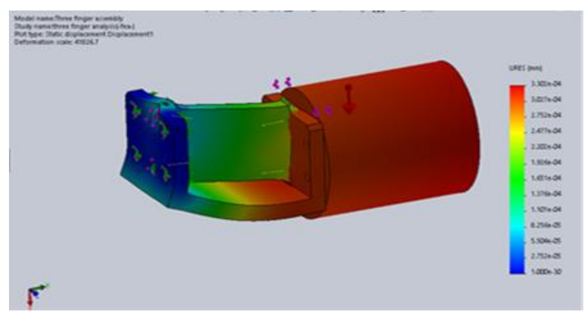

Fig. 12. Deformation of data under the loads

It can be seen that the maximum value of stress is well below the yield strength of the material which is Aluminium alloy. The maximum deflection is also under the safe margin. The maximum stress in the material is 7.096 Mpa and maximum deflection is 0.0003 mm.

The bolts used for attaching the support plate to the bracket are shown in the picture above.

The initial pre-tension on each bolt applied was 100 N for analysis point of view and the forces generated in the bolts as a result of the applied external load is shown above. The axial force is 103 N.

Tensile stress = force/Area

Stress = 103/(pi*d^2/4)

= 103/ (3.14*4*4/4)

= 8.200 N/mm^2

= 8.200 Mpa

The bolt chosen is of plain carbon steel having a tensile yield strength of 270 Mpa.

B. Misalignment compensation assembly

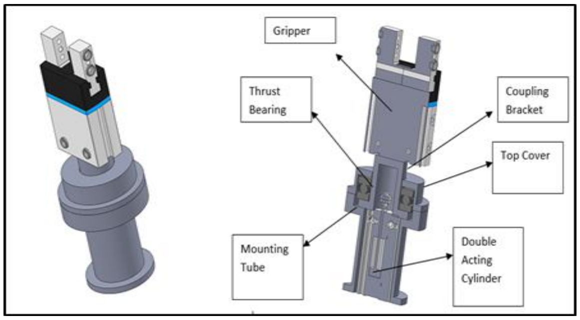

Fig. 13.

- The prototype of the design is shown above and is a rough idea of the mechanism. As per the A component must be designed which attaches to the cylinder rod and presses the coupling bracket.
- A set of thrust bearing must be installed below the coupling bracket, between the bracket and the mounting tube. This bearing gives a free motion to the bracket for axial rotation and reduces friction between bracket and mounting tube. It also takes up the axial forces due to the loads and the cylinder actuation.

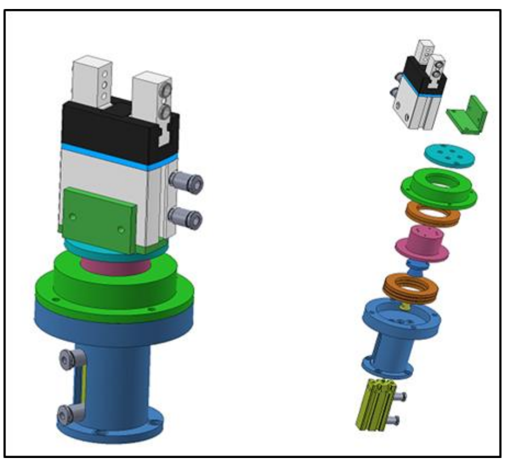

Fig. 14. Exploded View of Misalignment Compensation Assembly

1) Mounting Tube and Top Cover

As explained earlier the cylinder applies a force onto the coupling bracket which gets transmitted to the top cover. This force between bracket and top cover creates a frictional torque which counteracts the torque generated by the offset weights of the assembly components. Let's initially take a cylinder of diameter 6mm and appropriate stroke according to design. The cylinder selected is a Festo Double acting cylinder of dia 6mm and stroke 20mm.

P=F/A

F=P*A

F= 0.5*(pi*d*d/4) …. (5bar= 0.5 N/mm^2)

F= (0.5*3.14*6*6)/4

F= 15.3 N

This the force generated by the cylinder and transmitted to cup and hence to the top cover and coupling bracket.

As we have placed two outer races of thrust bearing in between the bracket and top cover, we have to consider the frictional torque generated between each contact pair. The inner surface of the race is sm0other compared to the outer and hence only one contact surface must be analyzed for the generation of frictional torque.

Frictional Force, f= Nu*(Normal Force) (Here, normal force= F)

f= .2*15.3

=3.06 N

The torque generated from this frictional force is

Torque, T=f*mean diameter

T= 3.06*38.5

= 117.81 Nmm

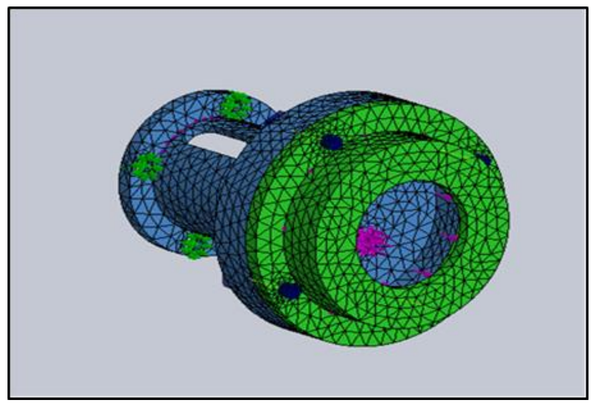

Fig. 15.

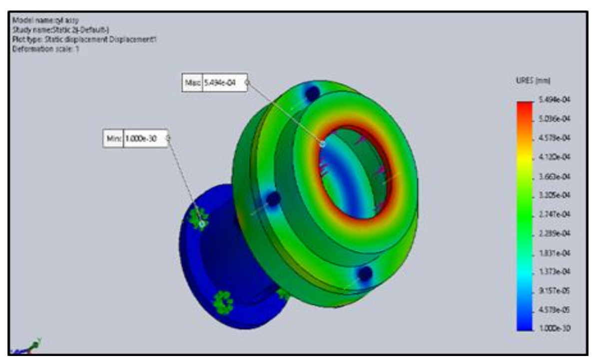

Fig. 16.

Four M4 bolts are mounting the two parts as shown below and applying 15.3 N of force normally over of the surface of the top cover and the reaction force on the mounting tube, the results are shown above.

The maximum von meiss stress generated is 8.8Mpa and is under the yield stress of the material. The maximum deflection is 0.00059 mm and is considered for the part. The bolts have a proof load of 1980 N and applied clamping load is 100 N which safely clamps the parts together and the bolts are safe.

2) Cone

Cone is the part which is attached to the cylinder rod and is pressed into the cup once the cylinder actuates. This cope and cone arrangement was done for proper alignment of the gripper to its desired center position. Coupling Bracket and top cover has a clearance between them for its rotation and which leads to offset of the axes of both this cup and cone arrangement eliminates the axis offset of coupling bracket and aligns it to the center. A force of 15.3 N is acted on the surface of the cone and the results are shown below.

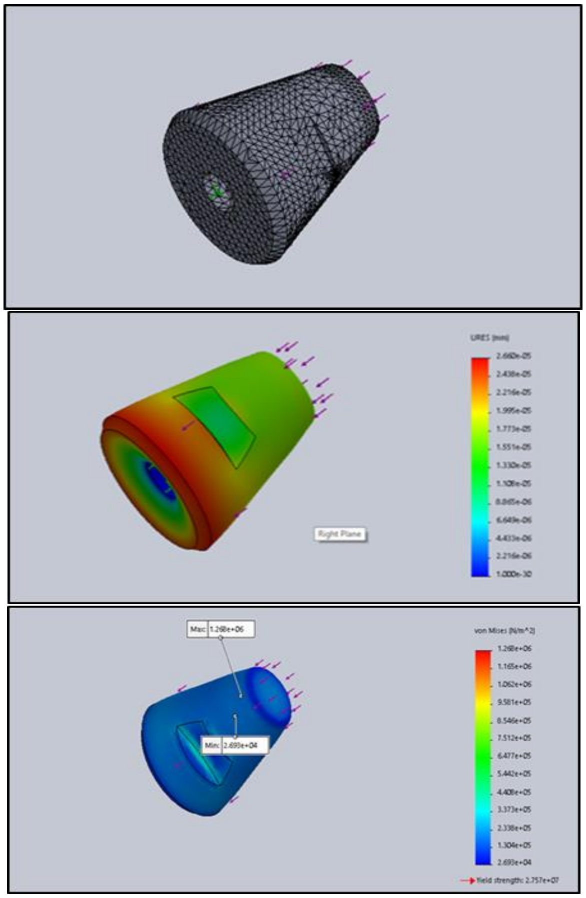

Fig. 17.

As seen from the results the maximum stress generated is 1.2 Mpa and the maximum deflection is 0.000026 mm which are under the safe conditions.

3) Coupling Bracket

Coupling Bracket and the cone are attached to each other using bolts. The bracket is held in place by the top cover when the cylinder actuates and force is applied on the cup part. Cup attached to the bracket using bolts and it acts as a seating place for the cone which ensures proper alignment of the coupling bracket with respect to its axis. As per the pictures shown below, the surface which is in contact with the thrust bearing and top cover is fixed and a force of 15.3N which is acted by the cone onto the cup part.

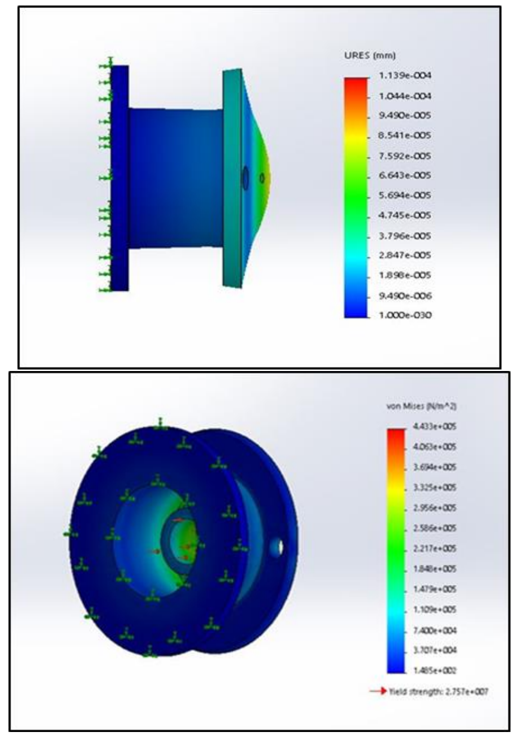

Fig. 19.

Materials	ABS(Acrylonitrile Butadiene Styrene)	Aluminum (EN AW 6082)	Aluminium (EN AW 7075)
Chemical composition %	Acrylonitrile = 15 to 35% Butadiene = 5 to 30% Styrene = 40 to 60%	Copper=0.10 Manganese0.4-1.0 Zinc=0.20 Chromium=0.25 Silicon=0.7-1.3 Iron=0.5 Magnesium=0.6-1.2 Titanium=0.10 Aluminium=Rem	Aluminum, AL=90 Zinc,Zn=5.6 Magnesium, Mg=2.5 Copper, Cu=1.6 Chromium, Cr = 0.23
Density	0.9 – 1.53 g/cm^3	2.70 g/cm^3	2.8 g/cm^3
Melting point	No true melting point	570-660°C	483°C
Tensile strength	46 Min MPa	300 Min MPa	360-540 MPa
Yield strength	48 Min MPa	255 Min MPa	240-460 MPa
Elastic modulus	2.6 GPa	69 GPa	70-80 GPa
Poisson's ratio	0.35	0.33	0.33
Elongation at break	3.5 to 50%	9 %	17%
Hardness	100 HB	91 HB	60HB
Thermal expansion	81 to 95 10-6/K	23 x 10-6/K	23.2(10-6/K)
Thermal conductivity	0.1 $W m^{-1}K^{-}$	184 $W m^{-1}K^{-}$	130 $W m^{-1}K^{-}$
specific heat capacity	1.96 - 2.13 J/g-°C	897J/kg K	860J/kg K

As per the results shown above the parts are safe from von meiss stress and deflection point of view.

6. Material Selection

The expected outcome of this material selection process is to identify one material with properties that meets the functional requirements of the components such as strength, stiffness, and hardness of the materials.

A material selection involves the following five steps in general,

1. Identification of the design requirements
2. Decide the materials selection criteria.
3. Identify all optional materials.
4. Evaluate candidate materials.
5. Material finalization.

The design requirements in this project are performance, reliability, cost, shape and industry standards. Since the material needs to be machined as a 3D model with the help of additive manufacturing process. The ABS material is cheaper and easily available locally. Material should have good thermal and mechanical properties.

The materials selection criteria are based on the design requirements identified earlier. The selection criteria are high hardness, high yield strength, high fatigue strength and better thermal expansion of the material.

Based on the criteria, steel was neglected from the selection process as it had low thermal conductivity. Different grades of aluminum were identified, and ABS material.

Used to manufacture the 3D model, since aluminum had good thermal and mechanical properties. The strength of aluminum was stronger than that of ABS. For the real product manufacturing purpose we are going for aluminium and for making prototype ABS material is used to manufacture.

The materials that were considered for the manufacturing process was EN AW 6082 and EN AW 7075. These 2 grades were compared with ABS grade and their properties were studied. The material was finalized after considering all the requirements criteria.

The main reason for considering these two grades of aluminum were their density of aluminum is very low, cost is cheap for aluminum, hence the weight of the component will be reduced. Since the density is less for the given strength, the specific strength of aluminum is high. Higher specific strength lowers crack initiation and propagation due to fatigue or impact to a considerable extent.

Advantages over normal gripper:

- Cost effective
- Reduces operation time
- Reduced maintenance cost

7. Conclusion

The main purpose of this paper was to design and develop universal adapter plate along with misalignment mechanism. The designed prototype was subjected to different tests. Both the mathematical and experimental results were verified and the margin of error was found out to be very less.

The 3D printed prototype was made using ABS material and mounted onto the KUKA KR C4 robot and various iteration of pick and place was done on the grippers whose results helped in the incorporation of changes and also in the betterment of the design.

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