DESIGN AND DEVELOPMENT OF A MULTI-GRIPPER FOR USE IN AN AUTOMATED ROBOTIC ASSEMBLY SYSTEM

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ABSTRACT

*The paper describes the design and development of a dedicated multi-function gripper for use in a robotic assembly system. It is based on the current automated assembly system operating in an actual manufacturing environment involving the assembly of parts to be incorporated in automated teller machines (**ATM**). The gripper that is fixed to the wrist of the robot arm is used to handle a set of ferrous shafts and rubber rolls to be assembled via suitable assembly mechanisms. A comprehensive description of the gripper design process is given from the conceptual stage to the realization of the prototype including testing and evaluation.*

1.0 INTRODUCTION

The end-effector of an industrial robot is the most important device attached to its wrist (end of the robot arm). A robot without an end-effector is like a human being without a hand. One can really imagine the difficulties and problems a person has to endure without having a hand to manipulate or sense objects desirably and effectively. Similarly, the end-effector of a robot arm is the vital part that actually accomplishes a variety of manufacturing tasks by manipulating the objects or work pieces either by means of a gripping mechanism or a tooling device within the robot's workspace. It is usual that in a manufacturing environment, the robot is used to pick-and-place objects, assemble components, weld together two different parts, machine work pieces, paint bodies and structures etc.[1]. It is thus essential that the end-effector should be carefully and properly designed before it is implemented to accomplish the desired tasks effectively.

The paper deals with the design and development of a gripper as an end-effector for use in an automated robotic assembly system. The assembly process involves mounting of rubber rolls on shafts and the assembled parts known as shaft assemblies feature significantly in automated teller machines (**ATM**). It is the task of the gripper to handle the shafts and rubber rolls by picking them up from the feeders and placing them on to specific fixtures on a work table. We will consider the actual manufacturing environment in which the assembly system is based and the design of the proposed multi-gripper will be accordingly made with reference to this system.

The paper is structured as follows; the first part deals with the problem identification, design consideration and conceptual idea of the gripper. The next stage involves the proposed design with the details and this is followed by a description of the fabrication process of the gripper. The evaluation of the gripper is next outlined and discussed after it has been mechanically and electrically tested. Finally, a conclusion is derived and some suggestions for further work are highlighted.

2.0 IDENTIFICATION OF PROBLEMS

First of all, we identify the parts to be handled by the gripper i.e., the ferrous shafts and the rubber rolls. Figure 1 shows a set of the assembled components or shaft assemblies. As mentioned earlier, the assembly process involves mounting of rubber rolls on shafts. All in all, there are seven different types of shaft assemblies. In other words, there are seven batches of assembled products to be considered. To a certain degree, the process is quite complex because the shafts come in different lengths and there are two sizes of rubber rolls being used.

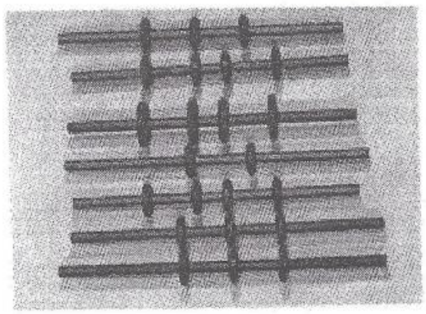


Figure 1 Shaft assemblies

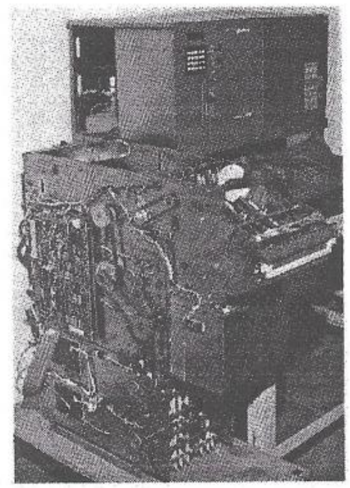


Figure 2 Inside an **ATM**. Note that the shaft assemblies can be seen at the upper and bottom right of the photograph

In the actual operating robotic cell, it can be seen that most of the work operations are executed by robot. The most time-consuming operation is picking and placing the rubber rolls via the robot's gripper. The robot picks up rubber rolls one at a time. The largest number of rolls to be picked is four and hence the robot needs to repeat the same picking operation four times. An alternative solution would be to pick the rolls simultaneously which would considerably reduce the pick time up to four times the present rate.

The assembled components are part of the mechanical features incorporated in the **ATM** which deal with handling of paper notes. Figure 2 shows the inside of the **ATM** as viewed from the front clearly exposing the shaft assemblies and other mechanical/electrical parts. The gripper used in the cell consists of two mechanical fingers mounted on a metal block that in turn is attached firmly to the stub of the robot's arm. The gripper can be made to open or close as desired by supplying compressed air into its pneumatic system on receiving signals from the controller. It plays five major roles during the assembling process:

1. pick and place shaft.
2. pick and place rolls.
3. latch and unlatch roll lock mechanism.
4. pick and place shaft assembly.
5. change shaft end stop.

Note that except for loading and ramming of shaft, all other operation are accomplished by the gripper. The gripper is equipped with two types of sensors, the first being a proximity sensor used to detect the presence of roll in between the fingers while the other one is a ferrous sensor to ensure the presence of a shaft.

3.0 THE CONCEPTUAL MULTI-GRIPPER

A special type of multi-gripper (fixed to the end of the robot arm) has been developed. This gripper can hold more than a single roll at a time (in the design - two, three or four rolls). In other words, the rolls can be grasped simultaneously. The number of rolls to be handled will depend on the programming of the robot itself. The other task that the gripper should perform is handling of shafts which come in different lengths and sizes. Thus a gripping mechanism to hold the shaft should also be appropriately designed.

The motion of the end-effector may be accomplished using an actuator (e.g., an electric motor, solenoid, compressed air, etc). Besides, smart sensory devices may be incorporated to increase the intelligence of system [2]. These sensors which are placed at strategic locations provide the essential information regarding the position of the objects to be handled. The data is conveyed to the robot's controller via suitable interface to effect its control action. A sensor can be placed at the gripper itself, another at the jig and also at the actuator (pneumatic assembly). The sensors are included to:

i. detect the presence and quantity of rubber rolls.

ii. place the rolls in their exact locations within the jig.

iii. enable the process to be executed sequentially.

A number of conceptual ideas has been developed, the final of which is described in the next section.

3.1 Design Consideration, Construction and Operation

The main design consideration of the multi-gripper is that it should be made of light-weight materials, involving small applied forces and simple in operation. All of these factors contribute towards a reduction in the production cost of the unit. In the assembly process, the operation of picking and placing of the rubber rolls is carried out at a fast rate and involves a light lifting load. Ideally, an electrically operated solenoid device has been chosen as the actuator since it can provide sufficient intermittent forces during its on-off cycle of operation [3,4]. Two grasping mechanisms utilising solenoids are considered in the study catering for the grasping of rubber rolls and ferrous shafts. They are described individually in the following paragraphs.

3.1.1 Grasping the Rubber Rolls

The operation of the gripper related to the grasping of the rubber rolls is direct and simple. It utilises the concept of a lever mechanism. A load derived from the magnetic pull of the solenoid's plunger is applied at the centre of the unit causing the shorter end of the fingers to tilt upward. This force is transmitted to the other end of the fingers thereby producing a grip or `close' action. Any components or work pieces placed in between the fingers will be firmly gripped. A sketch of the gripping mechanism is illustrated in Figure 3 (a single unit) while the `complete' feature is shown in Figure 4.

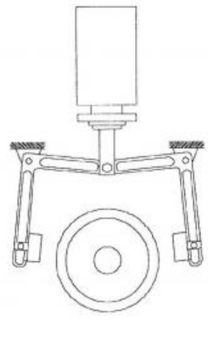


Figure 3 A gripper unit

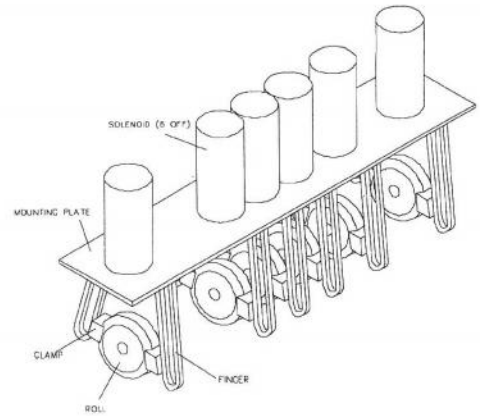


Figure 4 A 'complete' unit

There are six such units arranged in a single row and mounted on a light rectangular metal plate using screws. The proposed gripper consists of a number of individual units comprising a tubular solenoid, twin `bell-crank' levers acting as the fingers, a pair of clamps and attachments. The end of the solenoid's plunger is connected to the shorter end of the lever while the clamp is attached to the longer section of the lever. A pivot is located at the lever's `meeting point'. The forces involved may be easily calculated using principle of mechanics as shown in the following section. The fingers are left `open' by switching off the electrical supply to the solenoid thereby returning the gripper to its original position. The simultaneous gripping and releasing action is made possible by applying simultaneous and intermittent electrical signals in the form of **dc** voltages to the appropriate solenoids. Figure 5 shows a side view of gripper that is gripping the rolls in between the fingers. As a practical illustration, assume that two rolls are to be picked up by the gripper and that the rolls are strategically placed in between the fingers of solenoid units 5 and 6. Voltages are then applied to units 5 and 6 to activate the units causing the respective fingers to clamp the two rolls as required and ready to be lifted. Other solenoids at this point in time are inactive. The release of the rolls is accomplished by simply switching off the power source once the gripper has reached a suitable destination. The rolls drop automatically due to the effect of gravity when the fingers are opened.

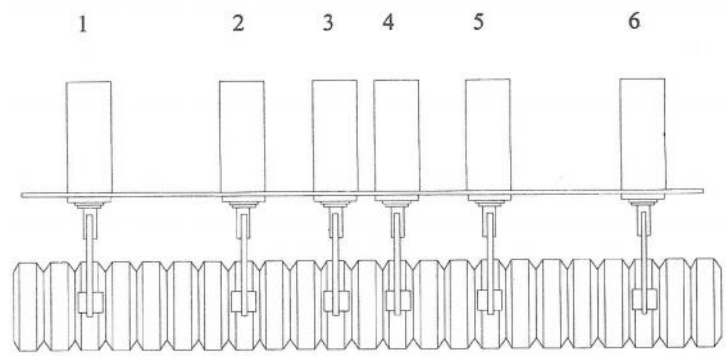


Figure 5 A side view of the gripper

3.1.2 Grasping of Ferrous Shafts

As for the shafts, an electro-magnetic solenoid device is proposed to provide the gripping force due to the property of ferrous material of the shaft itself. A model is simply chosen that can accommodate the weight of the shaft (plus taking into account a suitable safety factor). The operation of the device is such that when an electrical signal is provided, the solenoid acts as an electro-magnet which can pick up the ferrous shaft. Two such solenoids are proposed in the design to cater for the lifting of shaft at its two extreme ends for stability and more holding power. When the power is switched off the shaft will be automatically released by gravitational effect. A sketch of the multi-gripper with the electro-magnetic solenoids fixed at two locations is shown in Figure 6.

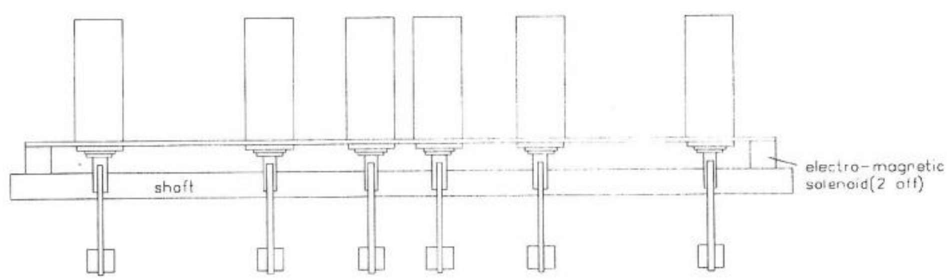
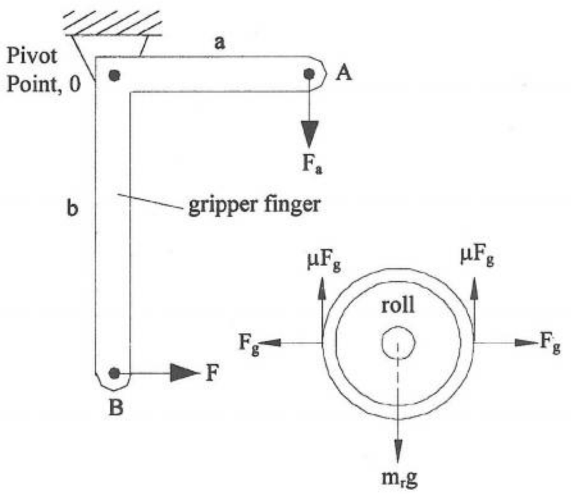


Figure 6 Electro-magnetic solenoids attached at the two ends of gripper mounting plate to lift the shaft

From the above description, it can be seen that the design of the multi-gripper requires that some of the present components of the system need to be modified or improved. The degree of modification will depend on the development of the whole system.

4.0 CALCULATION OF FORCES

It is important to determine the load that the gripper's actuator needs to lift the work pieces (shaft and rubber roll) effectively. Consider the diagram shown in Figure 7 which refers to the forces acting on one of the two symmetrical sets of the fingers (for grasping rubber roll) and also Figure 8 showing the forces acting on a ferrous shaft.



(a) (b)

Figure 7 Forces on a gripper unit (half) for grasping a rubber roll

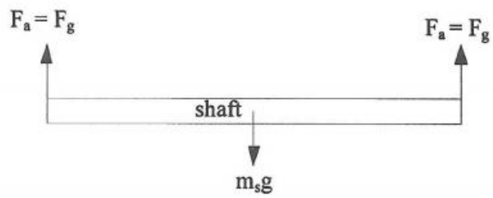


Figure 8 Forces on the shaft

With reference to Figure 7(a), a static analysis of the finger is given as follows:

Taking moment about the pivot point at O, we have

$$F_g\,(b) = F_a\,(a) \tag{1}$$

where F_a is the applied force from the actuator, F_g is the grasping force, a and b are the lengths of the fingers from the pivot point.

The forces present in the rubber roll as shown in Figure 7(b) can be described as:

$$n\mu F_g = m_r g \tag{2}$$

where n is the number of contact surfaces, μ is the coefficient of friction between the contact surface of rubber roll and the finger (metal), m_r is the mass of roll and g is the acceleration due to gravity. Letting, a = 24mm, b = 40mm, g = 9.81m/s^2, n = 2, μ = 0.3 from [5] and m_r = 40g the grasping force can be determined using Eqn. (2) as

$$F_g = \frac{0.04 \times 9.81}{2 \times 0.3} = 0.654N$$

Substituting F_g into Eqn. (1), the applied actuated force is calculated as

$$F_a = \frac{40}{24}(0.654) = 1.09N$$

Thus a force of 1.09N is sufficient to lift the rubber roll. Taking a safety factor of 2, the applied force is now calculated to be 2.18N. Browsing through the *Lucas NSF Solenoid*'s catalogue and data sheet [6], a tubular model provides a plunger stroke of 10mm and a load of 380g at the plunger. The load in *Newton* is obtained as

$$F = 0.38 \times 9.81 = 3.73\text{N}$$

This force is more than sufficient to grasp the rubber roll. Thus the solenoid model is selected as the actuating device for the gripper finger. A total of six tubular solenoids were employed in the design of the gripper.

Figure 8 is referred in the following analysis of static forces on the ferrous shaft.

$$2F_a = m_s g \qquad (3)$$

where F_a is the applied force (or lifting force, which is equal in magnitude to the grasping force F_g) and m_s is the mass of shaft.

If $m_s = 110g$, then

$$F_a = 110 \times 9.81/2 = 0.54N$$

Converting to gramme, a mass of 0.54/9.81 = 55g is calculated. Again, considering a safety factor of 2, the new effective mass is now 110g. Browsing through the catalogue and data sheet [6], a solenoid model of electro-magnetic latching type with a lifting (holding) force of 150g was chosen as this quantity is greater than the designed value of 110g. Two solenoids were used in the gripper to provide the lifting force at the two extreme ends of shaft.

5.0 THE PROPOSED MULTI-GRIPPER

The multi-gripper is a special feature of the assembly system. It is designed specifically in such a way that it can handle the rubber rolls simultaneously instead of handling them one at a time as does the conventional gripper on the present system. As a result, the pick operation of the rubber rolls is speeded up considerably. Figure 9 shows an isometric view of the multi-gripper.

The main parts of the gripper are described as follows:

5.1 Solenoids

The solenoids constitute the main actuators of the multi-gripper. Eight **dc** solenoids are employed. Six are of tubular and pull type while the other two are electro-magnetic latching type. The tubular solenoids are used to provide the gripping force on the rubber rolls while the electro-magnetic ones are for picking up the ferrous shafts. Activation of the solenoids is done through specially operated switches connected to a **dc** power source. The plunger of the tubular solenoid has been deliberately set and positioned to about 10 mm from its housing in order to facilitate the pulling action of the solenoid.

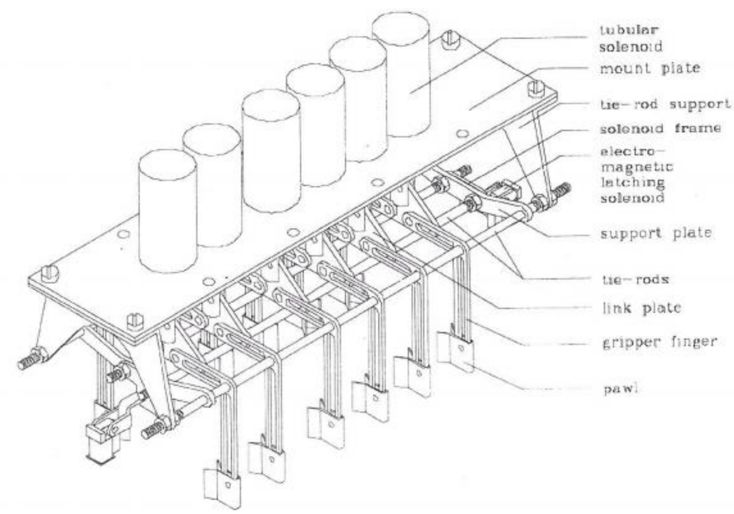


Figure 9 An isometric view of the multi-gripper

5.2 Gripper Mount Plate

This component is constructed from aluminium plate of about 1.60 mm thick. The tubular solenoids are mounted on the plate through a series of holes and tightened using nuts and rubber washers. It is important to note that these holes must be spaced accurately at a specified distance so that the solenoids will not be touching one other. The other small drilled holes are to accommodate the tie-rod supports and finger support.

5.3 Link Plate

As the name suggests, this serves as a `link' between the solenoid and the gripper fingers. A drilled hole at the top end is connected to the end of the solenoid's plunger while the two slots underneath it are for mounting the two fingers through their shorter sections. Again, the material chosen is aluminium which is relatively light, thereby providing a small load for the solenoids. Besides, it is also non-magnetic. The number of link plates to be used corresponds to the number of tubular solenoids.

5.4 Gripper Fingers

The finger is *L*-shaped and made of aluminium plate. The shorter section of the finger is connected to the link plate and the longer one to the clamp. Slots are drilled in the middle of the sections to make the finger much lighter. The two sections meet at the hinged point. A hole is drilled here through which a tie-rod is supported. The finger oscillates about the longitudinal axis of the tie-rod and thus it operates as a `bell-crank' lever during the operation. Nuts and spacers are used to connect the finger to the link plate to ensure that the relative position between the fingers are in the correct position corresponding to the position of the rubber rolls which are arranged in stack formation.

5.5 Tie-rod Support

The two identical tie-rod supports are placed at the two extreme ends of the gripper mount plate. They are fixed to the plate at the shorter bend ends using nuts. The two holes drilled at the longer section accommodate the tie-rods.

5.6 Tie-rod

In the gripper assembly, four tie-rods are used; the two longer ones are placed through the tie-rod support while the other two are located below the link assembly. The former act as fulcrum (or pivot) points for the gripper fingers while the latter serve to support the weight of the plunger and link plate assembly.

5.7 Central Support Assembly

The solenoid's plunger is not restrained from sliding out of its housing in the direction of gravity and thus a proper support is needed to prevent this. The support assembly comprises two parts; two tie-rods and three support plates. The tie-rods (shorter ones) are located through the holes of the horizontal section of the support plate. The two holes placed slightly above the horizontal section are meant for the longer rods. The bottom face of the link plate assembly touches the tie-rods, thereby providing the required support. At the two ends of the tie-rod, two solenoid supports (for the electro-magnetic type) are attached. Finally, the ends of the tie-rods are fastened using nuts.

5.8 Clamp (or Pawl)

Each gripper unit (with reference to the tubular solenoid) has two clamps or pawls, which are fastened to the longer section of the finger and mounted through the lower slots using screws. The function of the clamps is to provide the contact point between the gripper and the rubber rolls. The clamps are so designed that they enable the rolls to be grasped with sufficient force during the picking operation. Two types of clamp can be used and they are later tested to identify which one provides the better solution. The first type of clamps are made from a thin aluminium strip bent manually to shape. The other ones are manufactured from tufnol and specially machined to size.

5.6 Spacer

It is essential that the distance between each unit gripper is accurate in order that the gripper can pick up the correct rubber rolls, which are arranged in stack form. The other reason is to prevent the components from `wobbling' because of too much clearance. Hence spacers are used and placed strategically in the multi-gripper assembly at two locations. The first one is located at the upper finger section through the link plate. The second set of spacers are inserted onto the longer tie-rods. The spacers are made of acetal tubes, cut exactly to size. The inner diameter of the tube is drilled slightly larger than the diameter of the tie-rod or screw to facilitate clearance.

5.10 Comb

The combs provide additional positioning facility of the multi-gripper fingers at the lower ends. Two combs are used; each is attached by means of two metal strips mounted on the ends of the longer tie-rods. A series of rectangular slots are cut across the comb with sufficient clearance to accommodate the thickness of the fingers. During the operation, the fingers slide along the slots which act as guides, and thus enabling the clamps to grasp the correct rolls. The combs are made from thin perspex plate.

Note that the multi-gripper assembly is mounted on the stub of robotic arm by means of a specially constructed plate adaptor (see Figure 10).

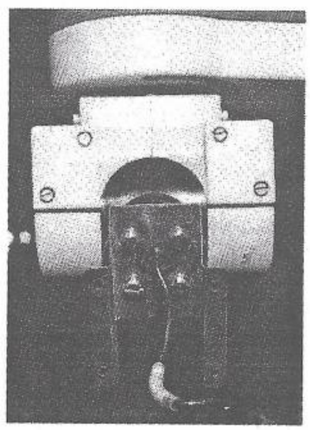


Figure 10 Gripper's adaptor attached to the stub (wrist) of a robot arm

6.0 TESTING THE MULTI-GRIPPER

Figure 11 shows the major components of a completed multi-gripper assembly connected to a **dc** power source.

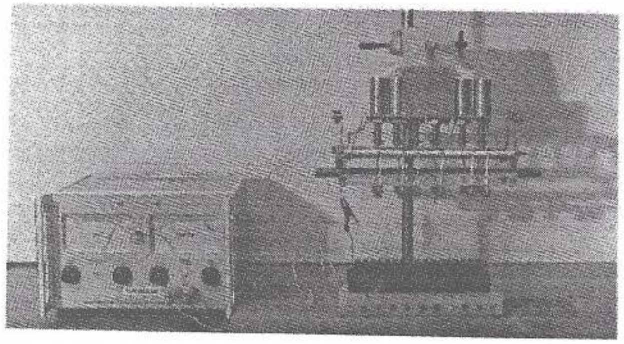


Figure 11 Multi-gripper connected to a power source

Note that the multi-gripper is dual-functional; the first function is to grasp a combination of rubber rolls, the second is to cater for the ferrous shafts. Since these two tasks are executed individually and not simultaneously, it is appropriate to describe the testing procedures separately.

6.1 Pick and Place Rubber Rolls

From Figure 12, it can be seen that the multi-gripper consists of a series of six pairs of `fingers' attached to tubular solenoids.

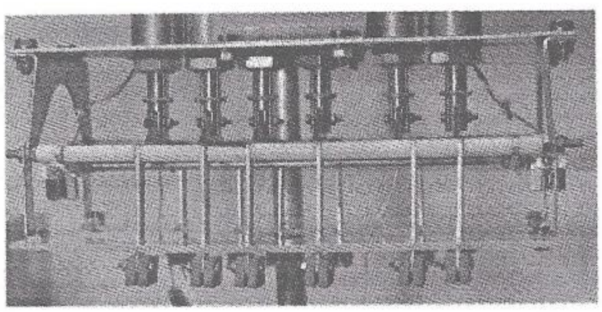


Figure 12 A close-up view of the multi-gripper

A suitably designed clamp or pawl was mounted at each lower end of the finger to facilitate the grasping of rubber rolls. The electro-magnetic latching solenoids were mounted at both ends as shown in the figure. The switching arrangements of the solenoids can be seen in Figure 13.

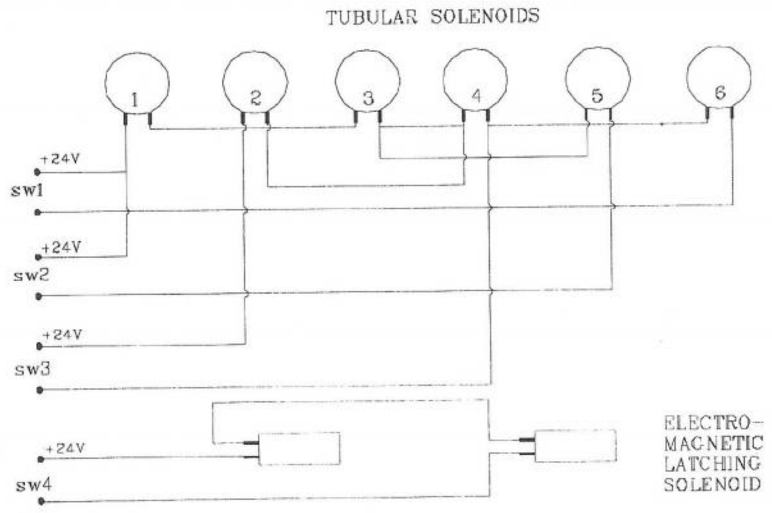


Figure 13 Switching circuits for the solenoids

The test procedure is as follows:

a. A retort stand was used to support the multi-gripper during the test procedure.
b. A plate adapter was mounted on the gripper mount plate and the gripper assembly was suspended through the drilled hole on the adapter.
c. A set of rubber rolls arranged in stack formation was placed on a suitable base. The relevant rolls (the ones to be picked by the gripper) were marked using a marker.
d. The rolls attachment was then placed at a suitable distance in between the gripper assembly.
e. The height of the gripper assembly with respect to the retort base was adjusted such that the gripper could easily grasp the rolls.
f. A dc power supply was set to 24 V.
g. The output terminals were connected to wire labelled `SW1'. This was to activate four tubular solenoids and consequently four rolls.

h. The power supply was then switched on.

i. Procedure (g) was repeated for wire connection SW2 and then SW3 to energise three and two solenoids respectively.

j. The power was switched off to de-energise the solenoids and release the grip on the rolls.

6.2 Pick and Place Shaft

This procedure is simpler than the previous one. The rig consists of a gripper assembly mounted on a retort stand as described in the previous section and a shaft rest.

The testing procedure can be described as follows:

a. A shaft was placed on the shaft rest.

b. The gripper assembly was placed over the shaft with the electro-magnetic solenoids positioned in-line and about 1 mm over the shaft.

c. The power connecting to SW4 was switched on.

d. The gripper assembly was manually brought vertically down so that the bottom sides of the electro-magnetic solenoids touched the shaft.

e. The shaft was then lifted.

f. The shaft was replaced to its original position by switching the power off.

6.3 Observation and Discussion

For the pick and place of rubber rolls, it was observed that when the power was switched on, the solenoids were activated according to the selected combination of rubber rolls, and the gripper fingers were able to clamp the respective rubber rolls. However, when the assembly was lifted, not all the rolls were picked and some dropped off during the lifting process. This was due to the inaccurate positioning of the gripper clamps with respect to the marked rolls.

To overcome this problem:

a. the critical distances were adjusted by means of screws on the central gripper link plate which joined the plunger and the fingers.

b. Some of the rectangular slots in the comb were filed off to facilitate the movement of the gripper fingers.

c. The clamping angle of the clamps was also made larger to provide more surface area for clamping.

When the above solutions were implemented and the testing procedures repeated, the multi-gripper performed satisfactorily and better than what was observed previously. It was found that the gripping force exerted by the solenoid on the rubber rolls was strong enough to pick the rolls efficiently. This could be demonstrated by trying to force open the fingers when the solenoid was energised. It was found that the rolls were firmly grasped by the gripper.

For the picking and placing of shafts, it was found that the shaft was lifted without any difficulty. When the solenoids were energised, they acted as electro-magnets and thus the ferrous shaft was firmly handled through electro-magnetic action. It was however discovered that the shaft rest needs to be modified. The shaft can be made to sit on a `soft' support with a degree of compliance using a set of compression springs instead of simply resting on a fixed vee-shaped support. This is to accommodate the vertical movements of the gripper assembly during the initial picking process and also to prevent the solenoids or the supports from getting damaged as the multi-gripper was brought to touch the shaft.

7.0 CONCLUSION

A special purpose multi-function gripper was successfully designed and developed to accomplish the desired gripping task. The tests conducted show that the gripping mechanisms are capable of handling the parts simultaneously and effectively with the use of minimal force compared to the conventional multi-purpose gripper used previously. This feature can contribute to faster assembly time and savings of the electrical energy. However, further works should be done to include the sensory devices and control mechanism via the robot interface.

REFERENCES

1. Groover, M.P ., Weiss, M, Nagel, R.N and Odrey N.G, "*Industrial Robotics - Technology, Programming and Applications*", McGraw-Hill Book Company, Singapore, 1989.
2. Heilala, J. and Ropponen, T., "*Mechatronic Design Concept for Intelligent Robot Grippers*", Procs. IMechE Int'l Conf. on Mechatronics: Designing Intelligent Machines, Mechanical Engineering Publications Ltd., UK, 1990.
3. H.E. & B.S. Benson Ltd., "*Choosing and Using Solenoids*", 1984.
4. N.S.F Limited, Ledex N.S.F Engineering Bulletin No. LX2, 1972.
5. Cook, D.I, and Pierce, D.N, "*Engineering Mechanics: Static*", International Textbook Company, USA, 1960
6. Lucas. N.S.F Engineering Data Sheet No. LX1, "*Solenoid Fundamentals*", April 1972, Sheet 1 of 3.

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