International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-9 Issue-4 November 2020

Conceptual Model of a Variable Cross-Section Brake Master Cylinder with Fuzzy Logic Controller

Vaibhav Bisht

***Abstract:** A Master Cylinder installed with a servo motor to vary the cross-sectional area of a Plunger Assembly is discussed. The motor is autonomously operated using a Fuzzy Logic Controller which uses sensor input(s) to position its shaft and subsequently change the cross-sectional area of the Plunger Assembly. This intelligent system helps achieve sufficient brake force under the dynamic requirement. The body is made of Al 7075-T6 primarily due to its high strength-to-weight ratio. In light of the corrosive nature of brake fluid at certain values of its pH, electroless-nickel plating of the Master Cylinder part components is also discussed. Dynamic seals made of EPDM rubber have been used due to the constant relative motion between different moving parts.*

***Keywords**: Fuzzy Logic, Servo Motor, Position Sensor, Electroless-Nickel, EPDM.*

I. INTRODUCTION

Brake biasing in itself has been an area of significant research in the ever-growing automobile industry. With the brakeforce required by each wheel varying due to several factors like dynamic mass transfer (due to sudden acceleration or deceleration), static weight distribution, and traction, multiple devices like the balance bar and proportioning valve have been rolled-out in the markets to aid this biasing effort. These consist of a manual drive to alter the brake pressure transferred to the connected wheel assembly. Such systems reduce the stopping distance by a significant margin and also help gain dynamic stability. With the development of sophisticated control ware, we have also been introduced to the revolutionary technology of EBD (Electronic Brakeforce Distribution). It consists of multiple sensors that constantly collect vehicle performance data and send it to an Electronic Control Unit (ECU). The ECU, which functions on several different mathematical equations and logics updates the final brake force that would be required by each of the wheels. Data on the updated brakeforce is then sent to brakeforce modulators which manipulate the brake fluid/ pressure transmitted to the wheel assembly upon the actuation of the brake pedal. The brake master cylinder also has been a crucial part of the braking system as it provides the required hydraulic leverage and acts as a brake force multiplier.

Revised Manuscript Received on November 20, 2020.
***** Correspondence Author
Vaibhav Bisht*, School of Mechanical Engineering, Vellore Institute of Technology Chennai, Tamil Nadu, India. E-mail: vaibhav.bisht.work@gmail.com

The cross-section of the master cylinder piston decides the multiplication factor and any change in it can significantly vary the final force acting on the wheels. An intelligent system that can work to alter this area can significantly lead vehicles to greater autonomy, enhance passenger safety, and also improve driving comfort.

The fuzzy logic has found a primitive place for use in such systems in the recent past. It works contrary to the conventional binary system of extremes, namely 1 and 0 (also seen as on & off or high & low). The fuzzy logic rather has modes between these extremes and can easily grant greater flexibility to the system to accommodate multiple modes of use. For instance, a motor run using the binary logic can either rotate at the maximum RPM or not rotate at all whereas using a fuzzy controller it can easily be tuned to run at the desired rotational speed or stay in a specific orientation, depending on sensor inputs or manual commands.

II. PRINCIPLE & FUNCTIONING

The principle of operation is similar to that of a single-piston master cylinder. A Plunger Assembly is used in place of a conventional piston and its area of cross-section can be altered by changing the rotational orientation of the shaft of the installed servo motor.

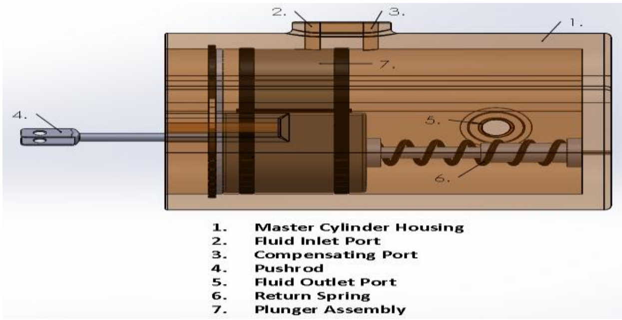

Fig. 1. Side-View

The pushrod is connected to the brake pedal and it converts the pedal's rotational force into a linear effort that actuates the brake system. The Plunger Assmbly, shown in Fig. 1. is moved linearly by this force of the pushrod and creates a hydraulic pressure (H_P) by acting on the brake fluid that comes in from the master cylinder's Inlet port. The Hydraulic Pressure (H_P) is derived using Eq. (1) :

$$H_P = F/A \qquad (1)$$

Where F is the force transmitted by the pushrod and A is the area of cross-section of the Plunger Assembly.

The brake fluid transmitting the hydraulic pressure (generated by the cross-section of Plunger Assembly) is then pushed into the brake line/hose through the outlet port.

The return spring constantly applies a restoring force on the Plunger Assembly and pushes it back to the initial position upon the release of the brake pedal. When the Plunger Assembly returns to its initial position, an air vacuum is created in the cylinder housing until the brake fluid moves back into it from the lines/ hoses. The compensatory port, which is directly connected to the reservoir passes brake fluid into the housing for this short duration of time to eliminate the chances of air collecting within the system. The compensatory port also puts brake fluid into the system to compensate for any volumetric losses occurring due to heating or cooling of brake fluid.

III. VARIABLE CROSS-SECTION

The feature of having a variable area of cross-section is seen in the Plunger Assembly which hosts the servo motor. The working of the Plunger Assembly as well as its salient features are discussed.

A. WORKING

The cross-section of the Plunger Assembly can be changed as and when required, using the installed servo motor. The Plunger Assembly consists of two parts, namely Plunger-I and Plunger-II, as shown in Fig. 2.

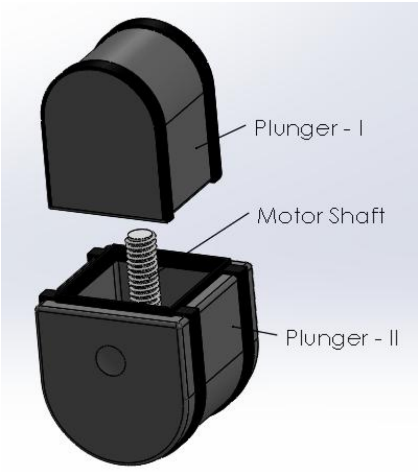

Fig. 2. Plunger Assemby

Plunger-II holds the servo motor whose shaft is present with an external threading (threaded directly or used with a threaded adaptor). Plunger-I on the other hand consists of a hole with an internal threading, as shown in Fig. 3.

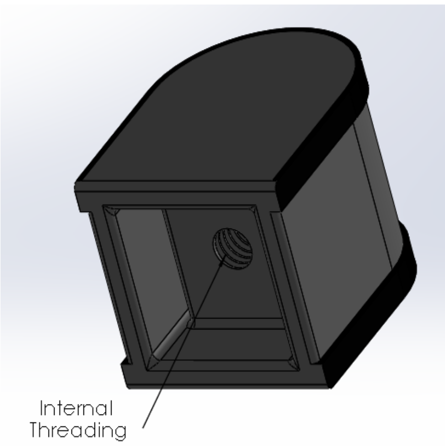

Fig. 3. Internal Threading in Plunger-I

The threading on the motor shaft then mates with the internal threading in Plunger-I, as shown in Fig. 4.

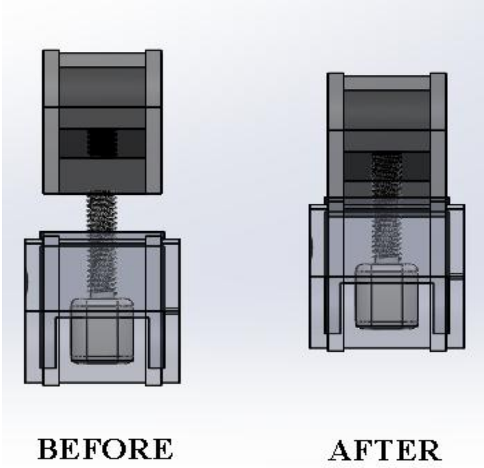

Fig. 4. Plunger Assembly Before & After Installation

The rotation of the motor shaft can move Plunger-I in the vertical direction which eventually changes the cross-sectional area of the Plunger Assembly.

B. DYNAMIC SEAL

Due to constant sliding motion within the Plunger Assembly and of the Plunger Assembly with the master cylinder housing, sealing is critical and a failure may have catastrophic repercussions. A dynamic U Type EPDM rubber (ethylene propylene diene monomer rubber) seal is used for the discussed purpose.

The Plunger Assembly comes installed with multiple dynamic seals, as shown in Fig. 5. Seal A, B, D and F are primarily installed to avoid leaks along the length of the housing, especially during the motion of the plunger assembly against the housing. While Seal C functions to avoid any leaks into the plunger assembly during the vertical motion of Plunger-I.

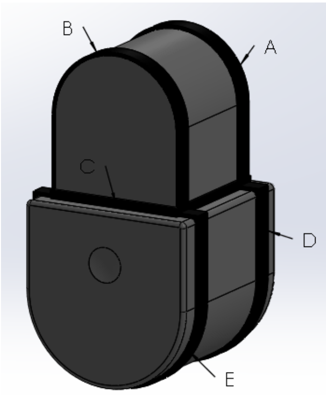

Fig. 5. Dynamic Seals Used in Plunger Assembly

For a perfect fit into the grove in the plunger assembly, the inner dimension of all the seals is 2% less than that of all the corresponding groves.

The squeeze of the seals has been another area of significant concern, especially due to the relative vertical motion in the Plunger Assembly. As seen in Fig. 6., variations in the cross-section of the Plunger Assembly would constantly require the seals to work at optimal levels over a broad range of squeeze.

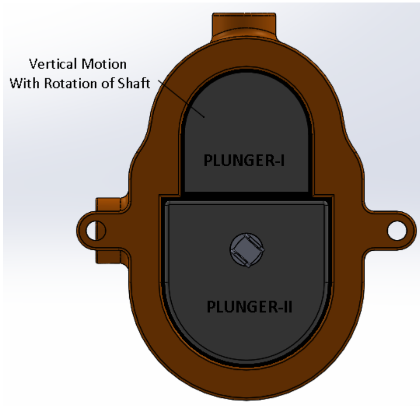

Fig. 6. Front-View of Plunger Assembly

The squeeze cannot be lower than a specific limit as it would then cause significant leakage, especially when considering the excessive amount of hydraulic pressure generated in braking systems. Whereas being in excess, the squeeze can cause pinching which would cause gaps for leakage. Too much of squeeze can also cause the seal to lose its resilience (by increasing compression set to values greater than the safe limit, usually 80%), a major issue considering the vertical motion of Plunger-I. Friction can also be problematic, causing significant wear & tear, compromising system efficiency as well as the component's service life, [1], [2]. It occurs in two kinds, the breakout friction (to be overcome to establish relative motion) and running friction (to be faced while in motion).

Considering the multiple conditions of use and the constraints, the dynamic seal is designed for a range of squeeze from 15% to 30%, with reference to the work done by [3].

C. MOTOR

A servo motor is used due to its sophisticated encoder-based feedback system that helps in gaining higher positional accuracy, which would be very important for use in a brake master cylinder as any variation or error in the final brake force may have undesirable consequences. It's high torque-to-inertia ratio also makes it highly responsive to command and helps maintain high operational efficiency, [4], [5]. Servo motors can also be obtained in smaller sizes when compared with stepper and DC motors, making them suitable for packaging in the given master cylinder design.

The motor has to constantly act at its peak rotational torque as it has to bear the weight of the plunger, act against the pressure of the hydraulic fluid, and constantly overcome the elastic resistance of the seal. A servo can easily be used to control to achieve this as it acts at the peak torque over a wide range of shaft RPMs, granting significant ease of control.

The servo motor also tends to retain its position against the action of any external force (rotational or linear). This is instrumental for use in the master cylinder design as Plunger-I may otherwise tend to move in the vertical direction upon the action of the external forces, causing unwanted variations in performance.

IV. FUZZY LOGIC CONTROLLER

In light of the various conditions of use, the brake system is required to be highly responsive to any change in the brakeforce requirement. It would be a very daunting task for the driver to manually position the motor's shaft to adjust for brakeforce. A fuzzy logic controller is therefore developed to determine the shaft's position using the collected sensory data.

It is developed using the Mamdani Approach and the sequence of operations is shown in Fig. 7.

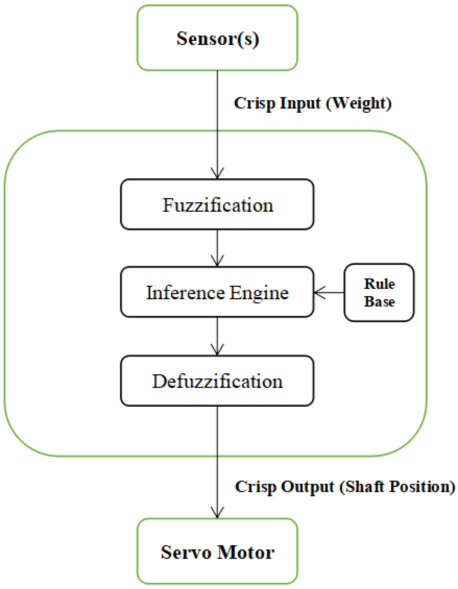

Fig. 7. Sequence of Operation in Fuzzy Logic Controller

A. SENSOR INPUT

The position of the servo motor's shaft is determined using the weight distribution of the vehicle. Linear potentiometer, a position sensor is attached to each of the shock absorbers to determine their linear displacement. The compression is used to attain the sprung weight acting on that wheel, which varies due to factors like passenger loading and luggage weight.

All the data is provided to the fuzzy controller as crisp input in real-time. This real-time feed is instrumental in updating the shaft position on a continous basis.

B. FUZZIFICATION

Upon being fed to the controller, the data given by the sensors is fuzzified. It is first converted to linguistic variables using the magnitude of the attained values. The output, the position of the servo motor's shaft is also processed as a linguistic variable.

Table-I: Linguistic Variables Used in Fuzzy Logic Controller

I/O	LINGUISTIC VARIABLE		
Weight (Input, kg)	Low (0-150)	Medium (150-350)	High (350-500)
Motor Shaft (Output, °)	in First-Section (0°- 60°)	in Second-Section (60°-120°)	in Third-Section (120°-180°)

The vehicle is taken to be carrying a load of 1000 kg. Each wheel is then expected to carry 250 kg under dynamic conditions of use and any variation in it would require the brakeforce to be altered.

The weight acting on the wheels is taken in terms of being low, medium, and high. Being a servo motor, the shaft can only move by an angle of 180 ° and corresponding to the weight acting on the wheel, the shaft is positioned by the controller so as to stay in any one of the three sections (based on the angle), shown in Table-I. The rotation ultimately satisfies the requirement of the area of cross-section of the Plunger Assembly, using the data collected from the sensor.

Membership Functions (MFs), consisting of the degree of membership of each of the possible inputs and outputs are created using the linguistic variables (in LabVIEW™) to determine the relationship between the two, as shown in Fig. 8. (APPENDIX A).

C. INFERENCE ENGINE

The Rule Base consists of multiple if-then conditions where the input is checked under the if-condition as the antecedent and the output is put under the then-condition as the precedent, as shown in Table-II.

Table-II: Rule Base

ANTECEDENT	PRECEDENT
IF 'Weight' IS 'Low'	THEN 'Motor Shaft' IS 'in First-Section'
IF 'Weight' IS 'Medium'	THEN 'Motor Shaft' IS 'in Second-Section'
IF 'Weight' IS 'High"	THEN 'Motor Shaft' IS 'in Third-Section'

The Inference Engine collects the input and tests it against the conditions given in the Rule Base to give the appropriate output.

D. DEFUZZIFICATION

The output that has been generated in the Inference Engine comes out as a part of a fuzzy set. It is required to be defuzzified and given out as a crisp output to be processed by the servo motor.

Using the Membership Function of the output, the Centre of Area method is used to perform the defuzzification operation.

V. TEST ARRANGEMENT

Using the linguistic variables and corresponding Membership Functions (MFs), an Input/Output relationship is developed in LabVIEW™. The shaft's position corresponding to the weight acting on the wheel can be obtained accordingly, as shown in Fig. 9. (APPENDIX B).

VI. SURFACE TREATMENT

Al 7075-T6 is chosen primarily due to its high strength-to-weight ratio. It also has superior machinability aspects and a high thermal conductivity which helps in dissipating heat quickly.

Aluminum alloys are safe from any chemical attacks in solutions having pH ranging from 4 to 9, [6]. But brake fluid generally lies in the range of 7 and 11.5, making Al 7075-T6 highly susceptible to such attacks. It is also prone to mechanical wear due to the presence of solid impurities or friction due to sliding motion between different parts for the functioning of the actuation mechanism. This combined deterioration of Al 7075-T6 used in the master cylinder is called Tribocorrosion (Tribo- Frictional Wear & Corrosion-Chemical Attack). This effect can cause multiple failures like internal leakages and mechanical deformations, leading to unwanted repercussions.

Tribocorrosion of Al 7075-T6 can be avoided by coating the internal parts and components with suitable protective material. Various methods can be used for coating metals, namely anodizing, hot dipping, galvanizing, Parkerising, cladding, autocatalytic plating, and electroless-plating, [7]. Electroless Plating is suitable for use in chemically aggressive environments similar to those created using silicone and glycol-based brake fluids, [8]. Electroless-Nickel, a mix of a Nickel alloy treated at around 90°C with 4-14% Phosphorous has been chosen for the operation.

Parts coated with electroless-nickel demonstrate a significant drop in corrosion rate when compared with the original state, [9]. Electroless-Nickel also has high tenacity, film continuity, a non-porous structure for operation, and leaves minimal residual compressive stress, [10]. Nickel in itself is not a sacrificial material coating like that of Zinc and Cadmium and hence grants a longer service life to the coated parts.

[11] presents the testing of three different Al 7075-T6 samples coated with electroless-nickel, electroplated-cadmium, and electroplated-zinc respectively. Hardness and tensile tests show the electroless-nickel coated samples stand out in terms of having superior physical properties. Table-III presents the increase in hardness, ultimate tensile strength, and tensile yield strength obtained by coating Al 7075 T-6 coated with a layer of 20 µm Nickel.

Table-III: Properties of Al 7075-T6 Before & After Electroless-Nickel Plating

Material	Hardness (Rockwell)	Ultimate Tensile Strength (MPa)	Tensile Yield Strength (MPa)
Al 7075-T6	84.33	608.15	559.19
Al 7075-T6 (Nickel Coated)	87	633.37	587.11

Concerning the coating operation, a proper surface pre-treatment procedure and process control are also crucial as these significantly contribute to giving a uniform layer thickness and proper surface adhesion, both of which are among prime concerns for surface treatment, [7].

VII. CONCLUSION

A Brake Master Cylinder with a Plunger Assembly capable of having a variable area of cross-section is hereby discussed. With it being a conceptual design, variations can easily be incorporated to satisfy different constraints varying from the size of the motor to the requirement of hydraulic pressure. The choice of Al 7075-T6 along with a coat of Electroless-Nickel together gives us superior part performance as well as life,

Retrieval Number: 100.1/ijrte.D5014119420
DOI:10.35940/ijrte.D5014.119420
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication

creating a scope for sale on the commercial scale. The design can also be customized very easily by using a wide array of sensors including load cells, hydraulic pressure sensors, and speed sensors. These can be incorporated effortlessly into the controller design under the scope of the growing MISO (Multiple Input Single Output) as well as MIMO (Multiple Input Multiple Output) control systems.

REFERENCES

1. Naresh Kumar Agarwal, Craig P. Lawson, “A Practical Method to Account for Seal Friction in Aircraft Hydraulic Actuator Preliminary Design”, Proceedings of the Institution of Mechanical Engineers Part G Journal of Aerospace Engineering, 2016.
2. AS. Rana, R.S. Sayles, “An Experimental Study on the Friction Behaviour of Aircraft Hydraulic Actuator Elastomeric Reciprocating Seals”, Tribology and Interface Engineering Series, 2005, Vol. 48, pp. 507-515.
3. Farid Al-Bender, Federico Colombo, Dominiek Reynaerts, Rodrigo Villavicencio, Tobias Waumans, “Dynamic Characterization of Rubber O-Rings: Squeeze and Size Effects”, Advances in Tribology, 2017.
4. Damir Žarko, Drago Ban, Davor Gorički, “Improvement of a Servo Motor Design Including Optimization and Cost Analysis”, EPE-PEMC, 2006.
5. A. Basu, S. A. Moosavian, R. Morandini, “Mechanical Optimization of Servo Motor”, Journal of Mechanical Design, Transactions of the ASME, 2005, Vol. 127 Issue 1, pp. 58-61.
6. Meyer Kutz, Handbook of Environmental Degradation of Materials, William Andrew, 2013.
7. Olawale Olarewaju Ajibola, Daniel T. Oloruntoba, Benjamin O. Adewuyi, “Effects of Hard Surface Grinding and Activation on Electroless-Nickel Plating on Cast Aluminium Alloy Substrates”, Journal of Coatings, 2014.
8. K.R. Tretheway, J. Chamberlin, “Corrosion: For Students of Science and Engineering”, 2018, pp. 1-201.
9. Olawale Olarewaju Ajibola, Daniel T. Oloruntoba, Benjamin O. Adewuyi, “Investigation of corrosion of cast aluminium alloy piston in brake fluid”, African Corrosion Journal, 2016.
10. Olawale O. Ajibola, Peter A. Olubambi, “Comparative effects of corrosion on electroless-nickel plated Al6061 alloys in DOT3 brake fluid”, International Journal of Engineering & Technology, 2018, Vol. 7 Issue. 2, pp. 927-934.
11. Ravi kumar V, Dileep BP, Mohan Kumar S, Phanibhusana MV, “Effect of Metal Coatings on Mechanical Properties of Aluminium Alloy”, AIP Conference Proceedings, 2017, 1859, 020037.

AUTHORS PROFILE

Vaibhav Bisht is a final year mechanical undergraduate student (B.Tech) at Vellore Institute of Technology Chennai. His research interests include Intelligent Systems, Additive Manufacturing & Machine Vision.

APPENDIX A

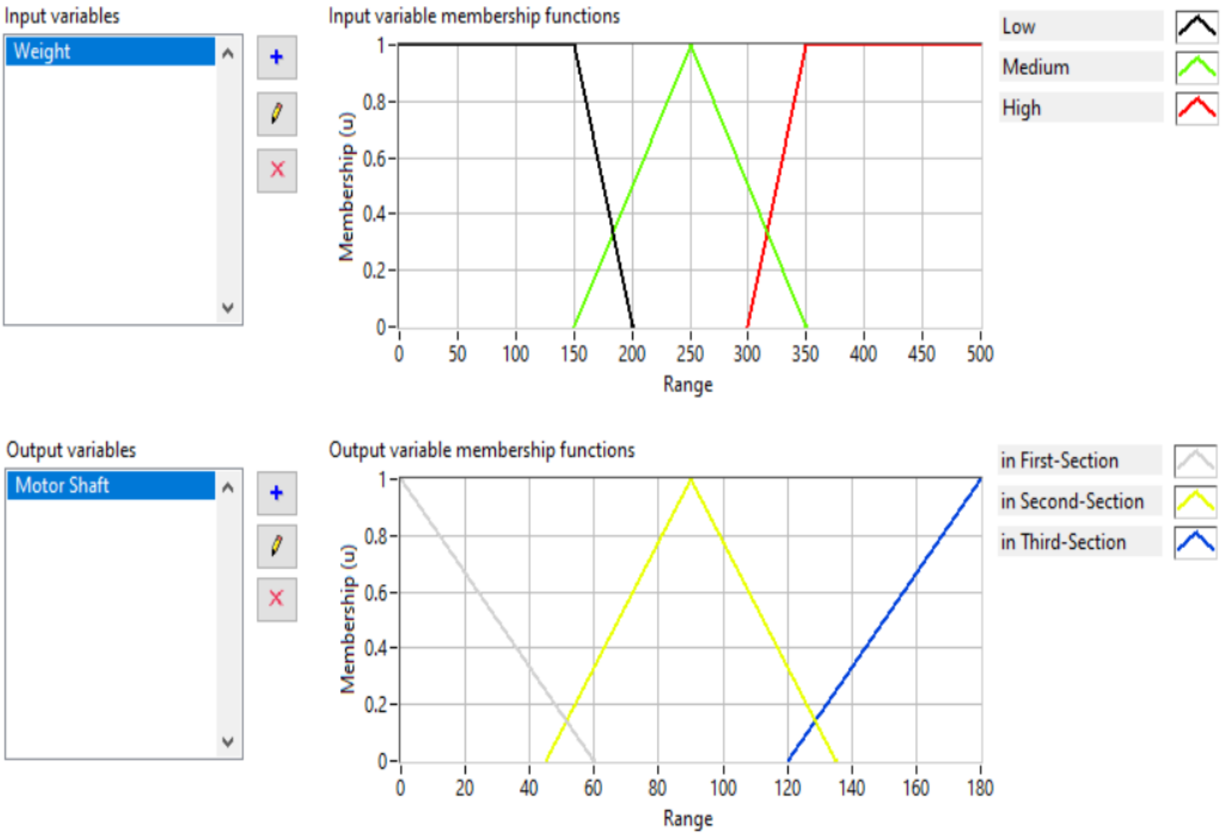

Fig. 8. Membership Functions of Input (Weight) & Output (Motor Shaft Position)

APPENDIX B

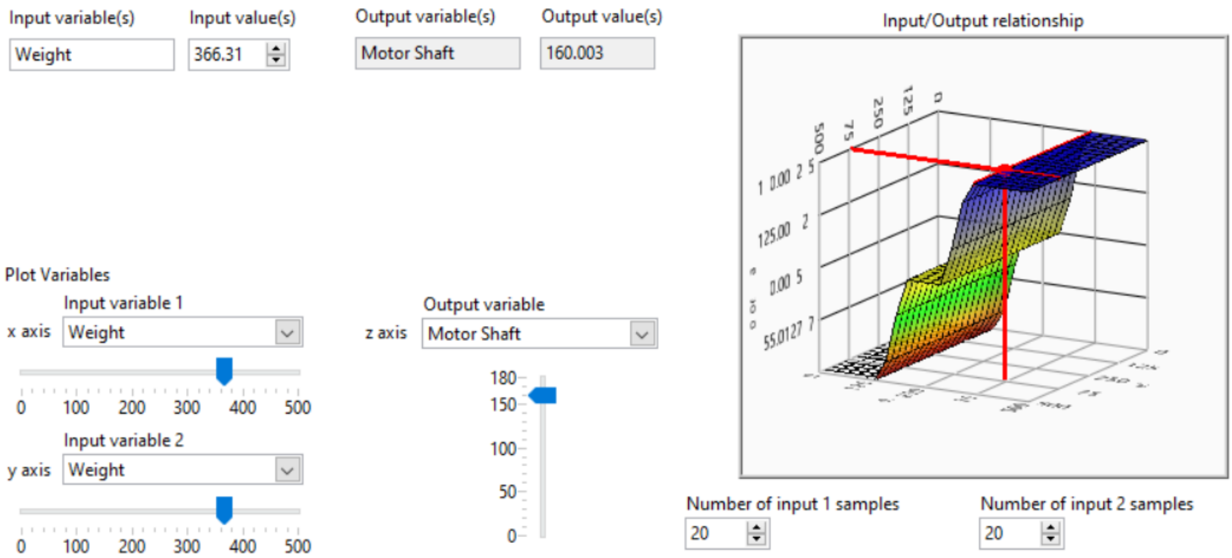

Fig. 9. Test System with Relationship Between Input & Output

APPENDIX C

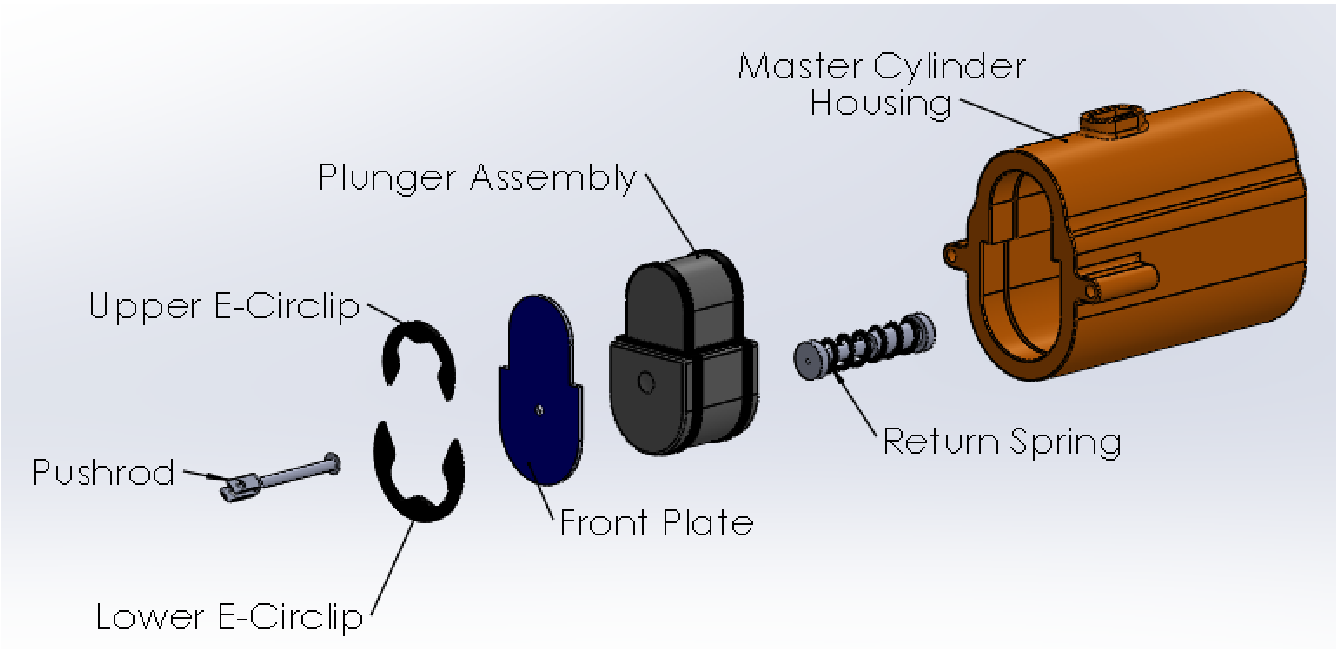

Fig. 10. Exploded Assembly View