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Analysis and Design of magnetorheological Permanent Magnet annular valve

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Abstract. usually, the rheological valves are working as a normally open valve. In this work, a rheological valve design is working as a normally closed (NC) valve. This feature is provided by the placement of a powerful permanent magnet that provides a magnetic field that impedes the movement of the smart MR fluids. Finite element modeling of this valve was carried out utilizing FEMM software, where the density of flux (B) and magnetic force (H) values were obtained stable along the effective gap. This valve operates at a variable flow rate based on the values of current applied to the coils. Where the relationship of current and flow rate is a linear relationship with increasing values of current, flow values increase. This design can be considered as an upgraded design of the rheological flow valves, which is characterized by great savings in wasted energy.

(This paper only has some of the figures in color if you read it on the internet.)

keywords

Annular flow gap, pressure drop, finite element analysis (FEMM) software, structural design,magneto-rheological (MR)fluid.

1. Introduction

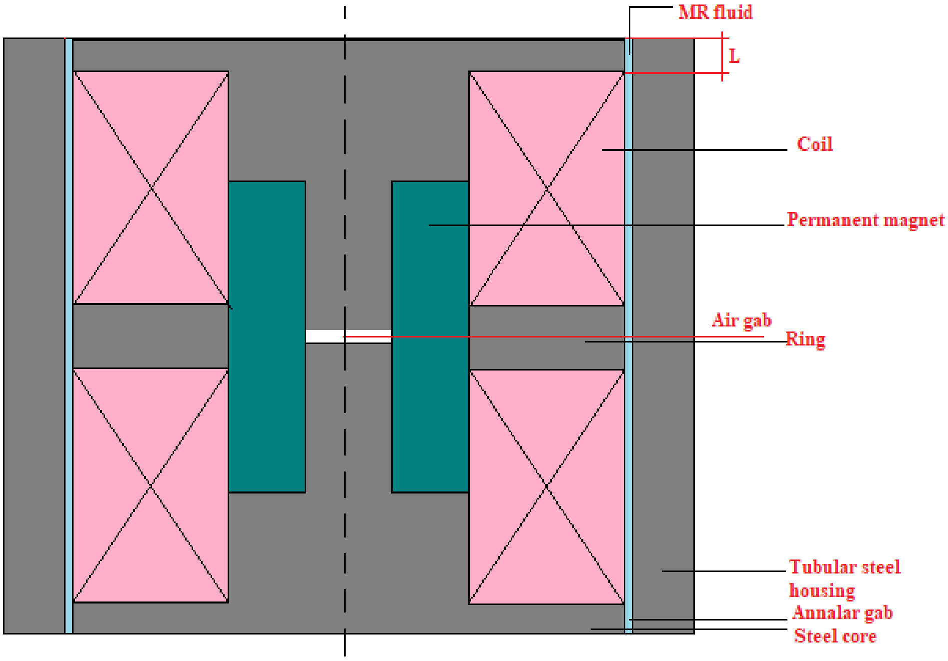
Magneto-rheological (MR) fluid is one type of intelligent fluid. It is a mix of iron powder and mild oil. It is the presence of a magnetic field that causes the fluid to exhibit the Magneto-rheological effect. Particles in the MR fluid form a chine, aligned with the field's axis. Magnetic-rheological (MR) fluids' yield stress will rise as a result of the iron-particle chains restricting fluid flow.MR fluids can be used to operate the MR control valve. Moving parts-free flow control valves are what the MR control valves are.

MR valves have been explored by several researchers. Analysis of an aperture with a solid orifice using an annular-circular flow route MR valve was done by Hu and colleagues in 2017. The design and prototyped through structural design to have an annular resistance gap, a radial resistance gap, and an orifice resistance gap, The valve's performance was excellent, especially with a large pressure drop, and it agreed well with the simulation results. The structural design of this valve has substantially increased its efficiency as a bypass control valve for an MR retarder because of its good pressure regulating capabilities[1]. The throttle-return valve concept for magnetorheological fluid is presented in this work. Valve design and field estimates were also discussed in this presentation on magnetorheological fluid[2]. Seid et al. in 2018 the design of a prosthetic knee MR damper valve were shown. The sewing phase course of conventional level-crushed mobile was primarily taken into account, as here is where the damping effect is most critical. To get the desired result, the damper's three government control parameters were found and optimized[3]. For tri magnetorheological (MR) clutches, this paper provides an integrated analytical-field design method. Analytical and finite element methods are used in the two stages of this procedure, which is constructed of 36 mathematical formulas (FEM). For B0 and Tmx, may achieve an accuracy of 0.2 and 2.6 percent, respectively, by using this approach[4]. The MR control valve, which functions as a hydraulic directional control valve, has been the subject of other studies. Salloom and Samad created the directional control valve. They've created a single unit that includes a set of MR valves for control. They demonstrated how the MR control valve works and how it is constructed[5][6]. Salloom proposed a design for MR the shut-off valve, usually the opposite of the existing valves, and added this design by adding permanent magnets, When MRvalve is locked for extended ages, the proposed MR valve saves powe[4]. For the time being, the focus of this research is on creating a novel, normally-closed design for an MR control valve that makes use of a permanent magnet. FEMM (“Finite Element Magnetic Software”) can be used to perform finite element analysis.

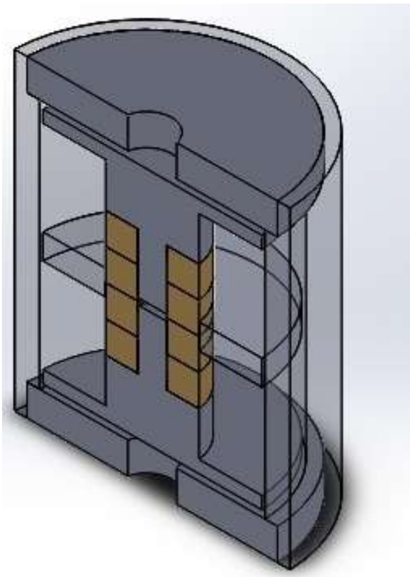
2. Building of an NC MR valve with double coil

A normally closed (NC) MR valve was designed to be small and easy to install to save energy and regulate the movement of the MR fluid.to get the best performance, so that a pressure drop is obtained, the pressure drop will be increased while keeping the dimensions small. The MR valve has a ring gap with a double external coil. The design consists of a tubular steel casing, a spool-shaped steel core, a steel ferrule, two discs, a strong neodymium permanent magnet, and a coil wound on a non-magnetic material as exposed in Figure 1. The design has a gap width g and gap length L. This strategy is suitable to use as a normal close (NC) controlling of direction MR valve. The NC MR valve length is short (38 mm) and The radius is (22 mm).

The magnets in the valve body are constructed of neodymium, one of the strongest types of magnets (N35). A low carbon steel cylinder with a 0.5 mm gap encircles the inside contents. The Teflon insulating material seals both ends of the valve body, allowing the smart MR fluid to enter and exit. Figure 2 depicts the valve's dimensions in more detail.



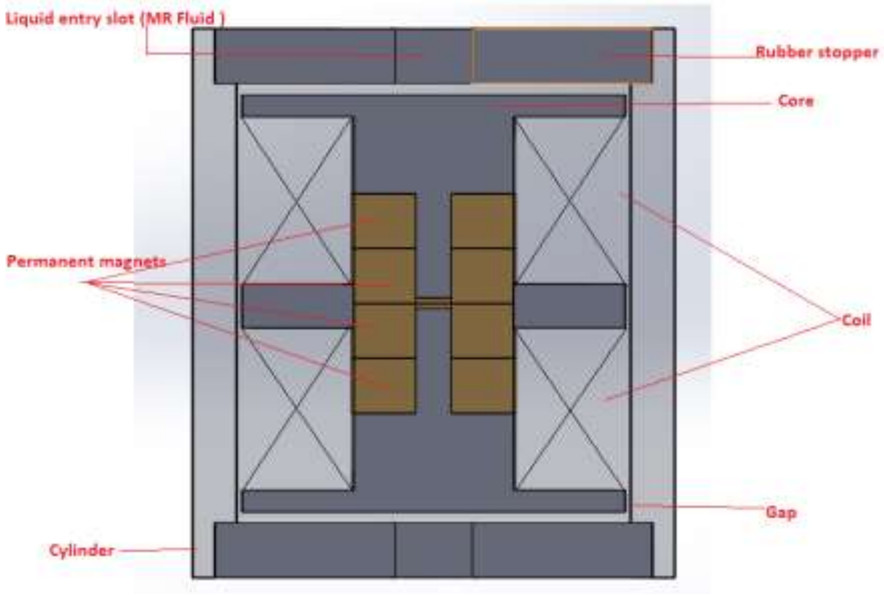
(a) The schematic of double coil NC MR valve with an annular gap.



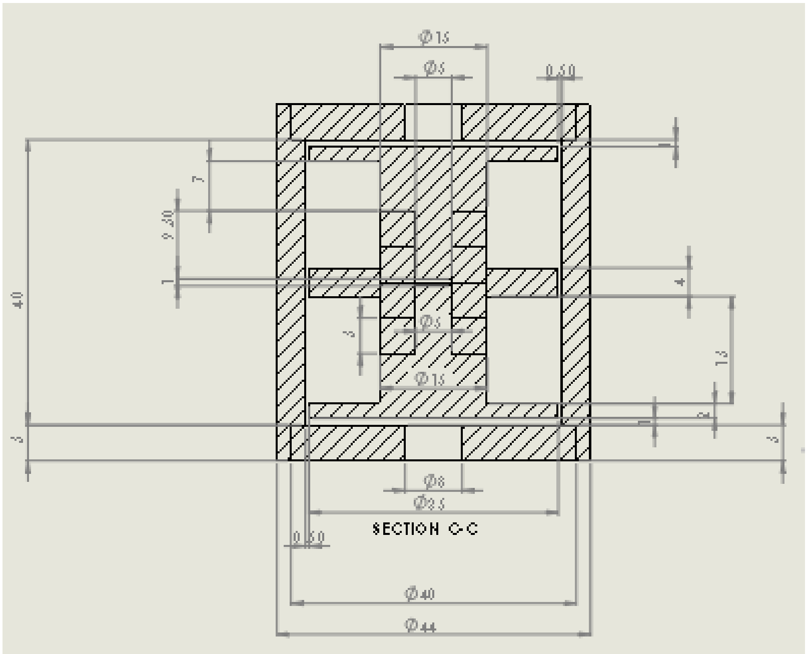
(b) NC MR Valve (element) building

Figure 1: Assembly of NC MR Valve (element).

For the steel rail, low carbon steel was used because of its low relative permeability (1018).



(a) NC MR Valve



(b): 2D of MR Valve

Figure 2: The Dimension of the NC MR valve.

3. The precept of work

With a magnetic field generated by permanent magnets embedded in the valve body, MR fluid is held together by chains of iron particles and prevented from passing through the valve in its normal state without shedding any current.

When a DC electric field is applied to the coils of the valve, an electric field that cancels the magnetic field's influence on the valve is formed. Allowing fluid to travel through, and the valve to entirely open is what happens when this happens. Adjusting the flow of fluid through the coils is done by increasing or decreasing the current. To do this, multiple coil connections and electrical circuits can be used depending on the valve position. To feed the valve's coils with a variable amount of electricity, the circuit has been designed.

As a result of the circuit's 12 volt DC input, the output can range from 0 to 2.5 amps. By connecting a rheostat to the valve's coil in series, and a three-position choose switch to relays, the specified position can be obtained.

4. Modeling

The methodology utilized to evaluate the functionality of the NC MR valve was as follows: In a single MR valve, the pressure playback mode was used as a recording mode based on rheological stress and magneto-rheological fluid flow, as shown schematically in figure3.

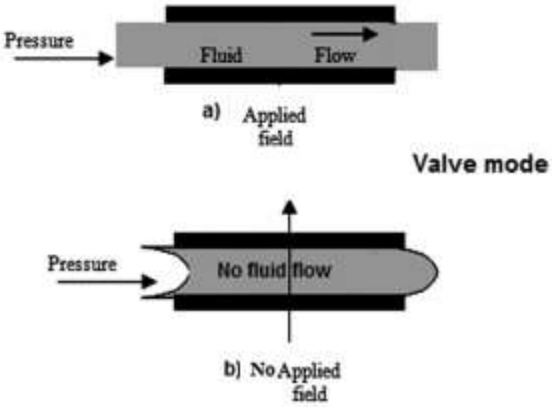


Figure 3: This diagram depicted the mode of Pressure of NC MR double coil fluid flaw.

The MR valve with annular ducts can be modeled through Eq.(1), figure 4 displays the flow of MR fluids in the NC MR valve channel thru the annular flow path [7].

$$\Delta P_a = \Delta P_\eta + \Delta P_\tau = \frac{6\eta Q L_g}{\pi R g^3} + \frac{c\tau_y L_g}{g} \qquad (1)$$

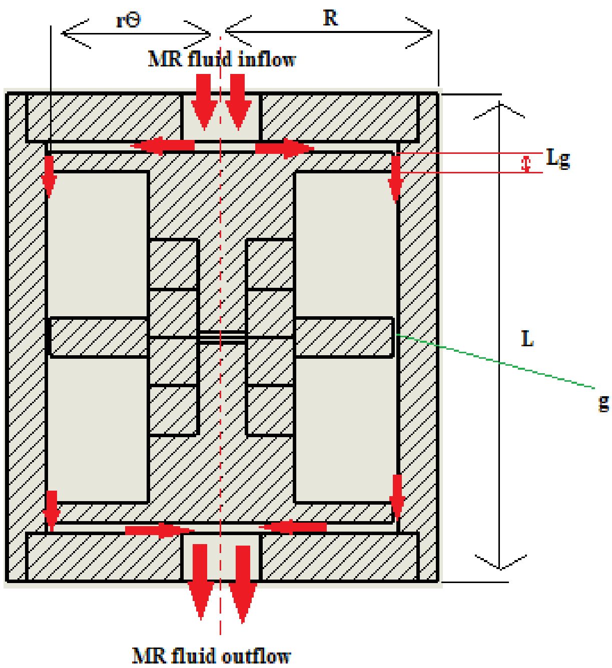


Figure 4: Modeling of the NC MR valve using annular flow paths plus double coil

This means that the MR valve's flaw resistance and annular fluid flow resistance multiplied by 8 equals the MR valve's total flow resistance. After plugging in this equation, we can calculate the pressure drop P that occurs when an MR fluid passes through the MR valve [5]:

$$\boldsymbol{\Delta P = 8\Delta P_a} \qquad \textbf{(2)}$$

$$\boldsymbol{\Delta P = 8\left[\frac{6\eta Q L_g}{\pi R g^3} + \frac{c\tau_y L_g}{g}\right]} \qquad \textbf{(3)}$$

Equation (3)'s viscous component includes the dynamic viscosity η (Pa.s), the flow rate Q(m^3/s), and the geometric dimensions Lg, R, and g in (meters). Based on the magnetic resonance valve's geometry, the pressure drop can be optimized. The shear stress created as a result of the applied magnetic field is represented by τ_y(N/mm^2), the equation's other parameter is reliant on the applied magnetic field. The plastic viscosity is considered to be 0.25 Pa.s. in the simulation [8].

To make a good NC MR valve, the density of flux in the flaid gap should stay the same. In comparison to low-carbon steel, "the permeability of the MR fluid is a lot less than that of low-carbon steel (such as two cores, bobbin, and flux return)". In this study, the distance is cut to 0.5 mm.

5. Analysis

When looking at equation 3, the only thing don't know is yield shear stress (τ_y). The pressure drop of a single MR valve needs to be looked into. The density of magnetic flux from the analysis is used to figure out the stress of yield shear (τ_y) of MR fluid in valve gaps. Equation 3 can be used to figure out how much pressure drops. In magnetic analysis, the tubular shape of the MR valve has a lot of different parts. To do a study, only FEMM can be used. It is not enough to look at the MR valve as a 2-D axisymmetric pattern because of its symmetry, as shown in figure 5. As shown in the diagram, a finite element method was used to model the magnetic circuit. Figure 6 shows the model that was made with the FEMM software.

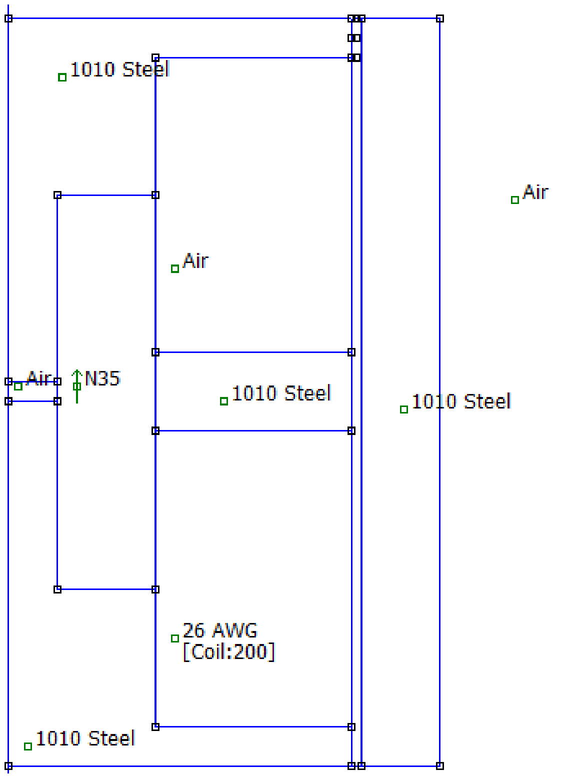


Figure 5:The FEMM dimensions of twin coil NC MR valve.

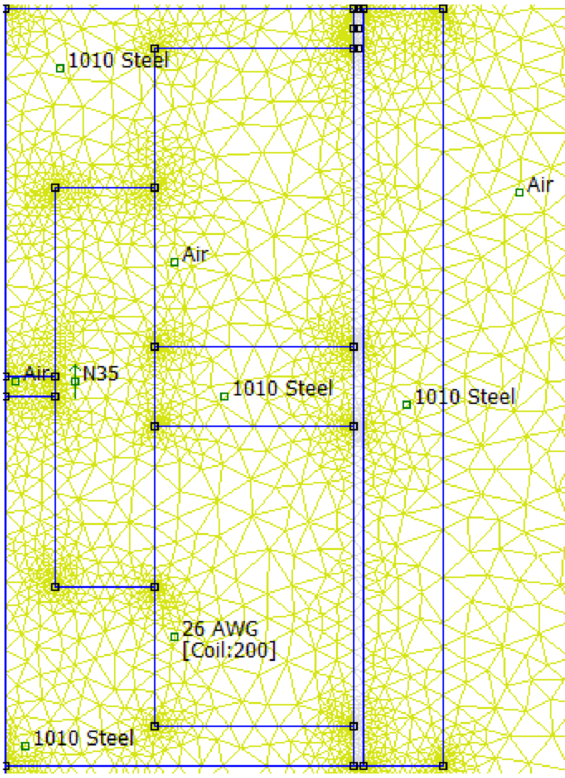


Figure 6: The model of twin coil NC MR valve in FEMM software.

Figure 7 shows the direction of the magnetic field in the double coil NC MR valve. There is a standard called MRF-132DG that says which MR fluids you can own. There are two points on the density of magnetic flux (B) vs. force of magnetic field (H) (BH) curve that belong to the MR fluid. These points are data for the FEM analysis of a new nonlinear material called MR fluid. It took all the magnetic coils to make a total of 200 turns. the coils got an output of 0 to 2.5 A at any given time. To make a model of an MR valve, MR water was used.[9] have used a multi-limit equation to figure out the shear stress.

$$\tau_y(kPa) = 52.962B^4 + 176.51B^3 + 158.79B^2 + 13.708B + 0.1442 \quad (4)\ [10]$$

Calculated by FEMM software, the density of flux in tesla sideways the valve gap is called B.

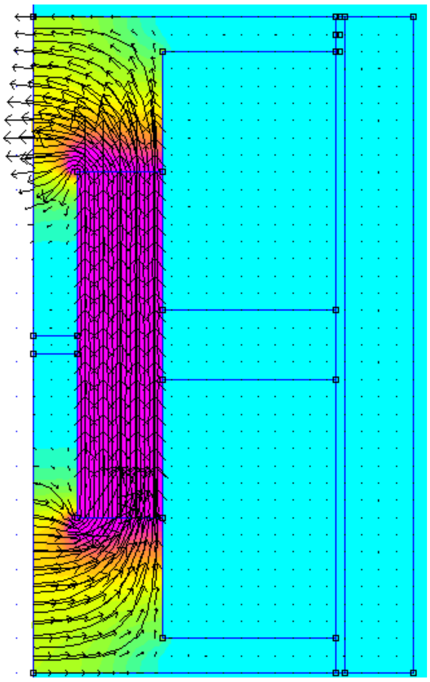


Figure 7: The double coil NC MR valve magnetic flux direction.

6. Results and discussion

A “finite element FEMM” study of the annular NC MR valve was done with FEMM software. This software was used to look at the valve. The annular NC MR valve can only do so much because the MR fluid has a limited yield stress. The magnetic strength of 310–360 kAmp/m is ideal. 47 kPa is the shear stress in the area where the yield is.

Figures 8 and 9 show the density of magnetic (B) and magnetic field (H) results of the MR valve's resolve test with the FEMM software, which is used to run the test. When No current (I=0A) means that the magnetic strength in the valve's active gap is called out. The “magnetic strength intensity”(H) was originate to be 350 kAmp/m based on the design of the annular NC MR valve. The proposed NC MR valve had the best H value. The _y was calculated by using equation 4 and the B that was found in the FEMM program. The $\tau_y$was 47kpa.

Figure 10 and Table 1 shows how the annular NC MR valves worked when they were simulated. A graph called figure 10 shows magnetic density made by currents in annular NC MR valve coils. When the puncture thickness is 0.5mm, figure 10 shows the density of flux caused by currents in coils of the NC MR valve. In this case, the flux lines are not in line with the flow of the MR fluid. At the valve gap distance, the magnetic flux density was almost the same. As the current in the valve coils increased, the magnetic flux density dropped. The shape of the valves was thought about to make it easier to control the magnetic domain. The magnetic field's saturation strength did not allow the maximum magnetic domain to go over.

Table 1 shows how the influx in annular NC MR valves changes with changes in current under different pressures. flow rate: As the current increases, so do MR valve flow rates. This shows that they are mostly affected by magnetization, which is determined by the coil current. As the current increases, the flow rate does too, until it hits 2.5 A. To figure this out, look at pressure drop charts. It is clear that when the pressure loss is at 2.5 A, the MR fluid is max flowing at 2.5 A. As a result, because the valve can open at full power, a 650 kPa operational pressure drop is used (2.5 A). When you change the current value, the rate of flow (Q) in the NC MR valve can be changed: a great current for a high flow and a low current for less flow. This is shown in figure 10. During the experiment, learned how a valve works and how the proposed electrical connection could be used to change the flow direction.

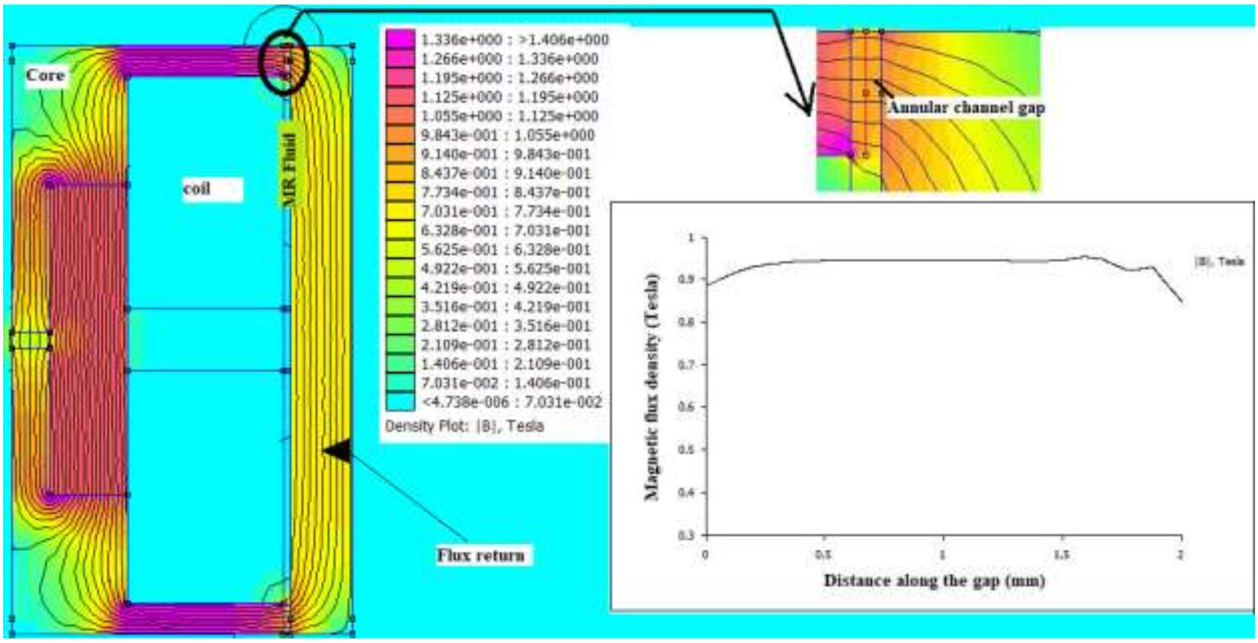


Figure 8: The annular NC MR valve flux density(B) result.

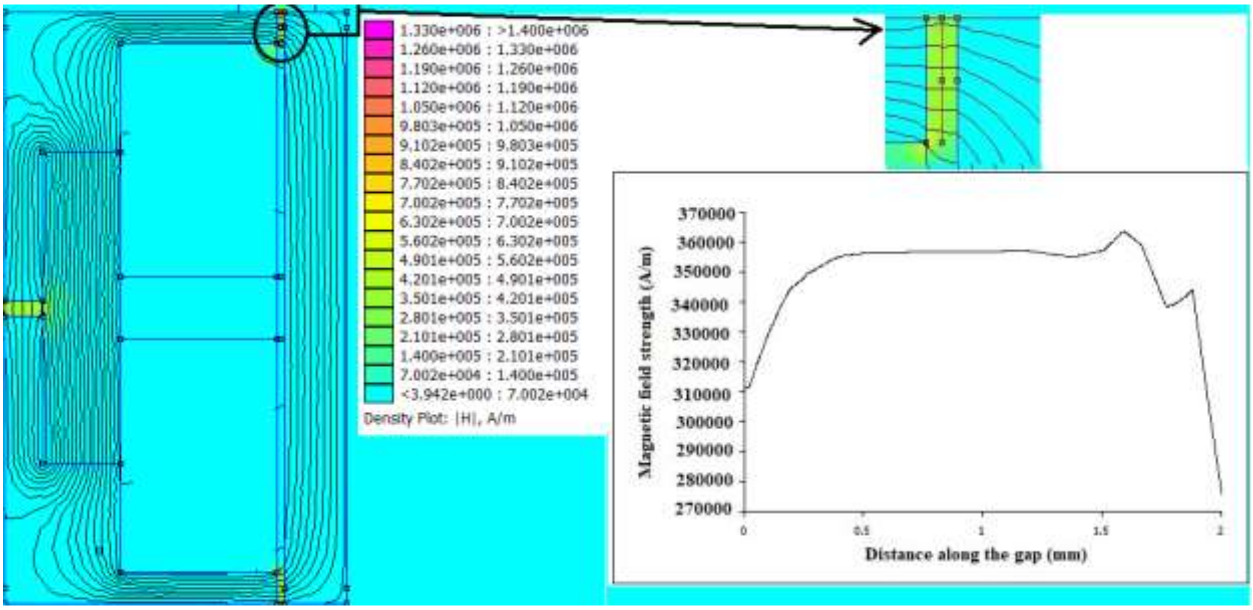


Figure 9: The annular NC MR valve magnetic field strength (H)result.

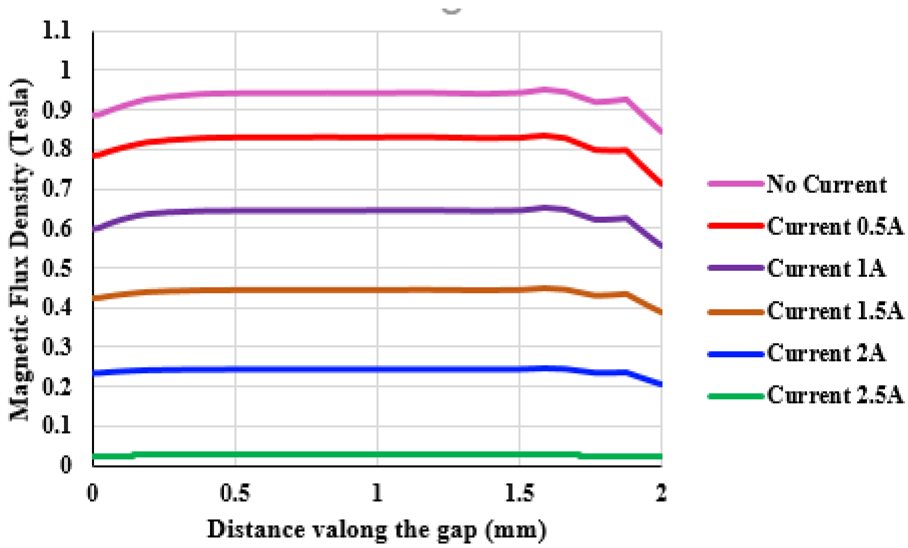


Figure 10: The magnetic density (B) along the annular NC MR valve gap.

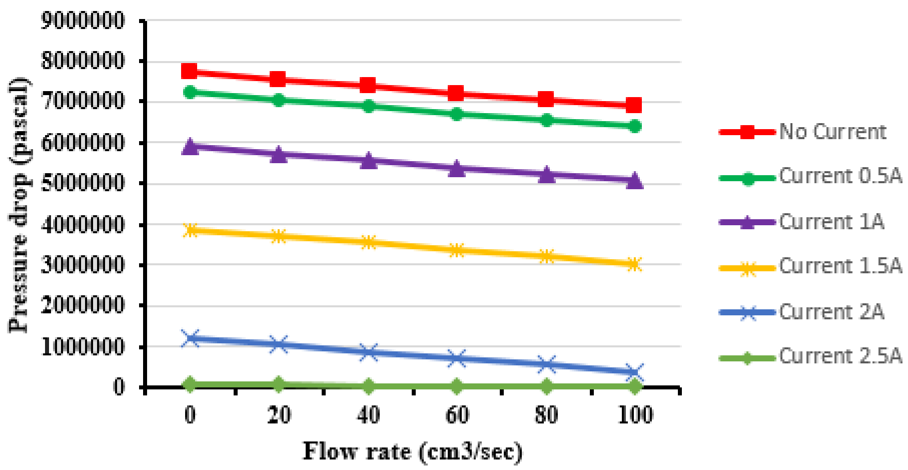


Figure 11: Relation between flow rate (Q) and pressure drop for different currents in annular NC MR valve.

Table 1: An annular NC MR valve has a relationship between the amount of current and magnetic flux in the fluid, the pressure, and the shear stress.

Current (A)	Magnetic Flux Density (B) (Tesla)	Shear stress τ_y	Pressure (bar)
0	0.945	48.1802	77
0.5	0.852	45.1210	72
1	0.673	36.849	58
1.5	0.443	24.2112	38
2.5	0.0267	0.6201	0.99

This valve has a rate of flow (Q) that can be changed by changing the current value. A high flow rate is caused by more current. Valve: When there is no current, the magnetic field from the permanent magnet closes it, and its magnetic flux intensity value is at its highest point, preventing it from flowing. This is what happens when there is no current: At 2.5 A, the B is 0.0267, which lets the MR fluid move. They show the magnetic flux values that were taken from the FEMM software in figures 12,13, and 14. They show that the current and flow rate and pressure drops aren't too far apart.

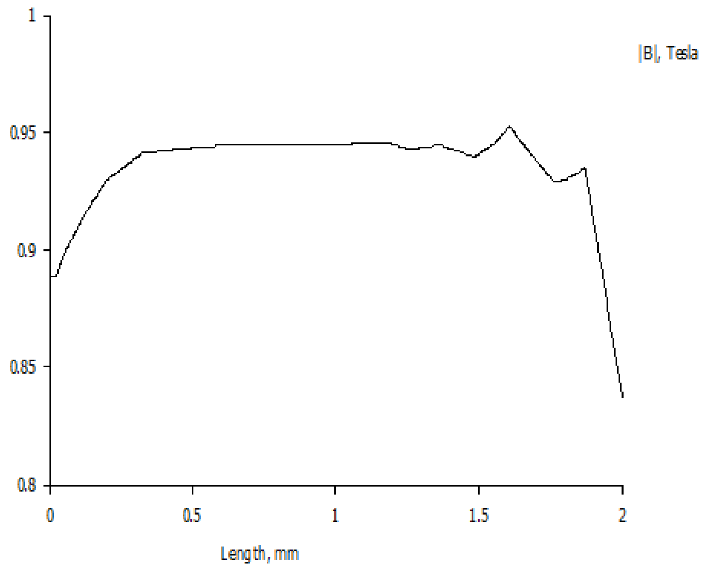


Figure 12:The FEMM software of the annular NC MR valve when I=0A.

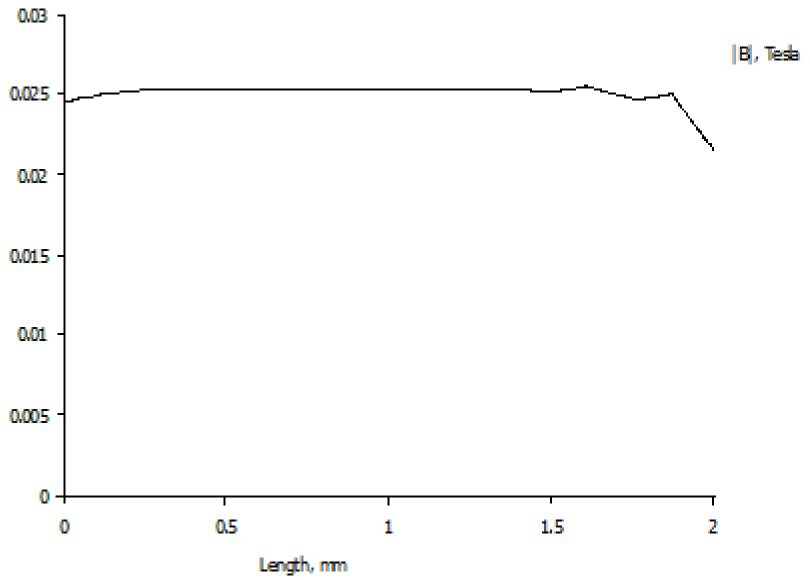


Figure 13: The FEMM software of the annular NC MR valve when I=2.5A.

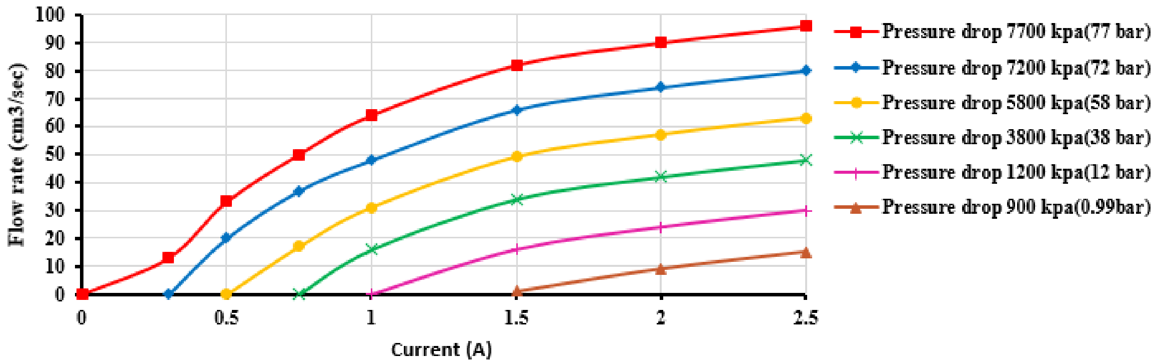


Figure 14:Reasonable relation between current and flow rate and pressure drops.

7. Conclusion

This paper talks about the structure and operating rules of an annular valve that is normally closed and can be moved by the properties of magnetic fluid. The valve is 38 mm long. each coil has 200 times. It has a powerful Neodymium (Ni) magnet, and it has a 2 mm effective gap along its length. The magnetic flux density (B) is measured when different values of the current are used. The flow rate went up with the rise in the value of the current, and the relationship between the current and flow rate was linear. The value of the pressure dropped with the increase in the current, which meant that the pressure and the current had an inverse relationship. The valve was very small, and the coil of the valve was outside the area where it worked, so it could be easily replaced if it broke. This is what happened when FEMM was used to run the simulation. Dissimilar values of the magnetic flux in the gap of two millimeters were found. At zero current, an ideal magnetic flux density (B) of around 0.9445 Teslas can be achieved when the valve is closed and the current value is 0. When the current is 2.5 A, the valve is fully open and is letting the most MR fluid through. The magnetic flux density (B) value is 0.0267 Teslas.

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