 ISSN: 0971-1260

Vol-22-Issue-16-August-2019

Performance Comparison of Magneto-Rheological Disc Brake In Constant & Step Shaped Configuration.

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1. Abstract:-

The braking action which is achieved by MR fluid which transforms torque by shear force is called as Magneto Rheological (MR) fluid brake. In the presence of an external magnetic field strength, MR rotary brake shows a quick change in response to its braking torque. In the present paper, two configurations of MR disc brake i.e., first with constant and second with step-shape clearance is analyzed and conclude how changes in the shape of the disc affects the maximum braking torque induce in the MR brake. This paper will pinpoint that, under the same excitation current the total magneto-induced torque of step-shape clearance MR brake are increased by 7%, as compared with produced torque of constant functional clearance brake.

Keywords:-Magneto-rheological fluid, magnetic flux, reluctance, shear stress, torque

2. Introduction

While designing MR brakes, the researchers always face the difficulty of providing the efficient torque in the small and required manner. Hence it is prime importance to figure out best possible arrangement which provides higher torque in small space. So on ANSYS platform a finite element model of 2-D axis symmetric rotary MRF disc brake i.e., first with constant clearance and second with step-shape clearance is made to examine and analyze. The structure specification for automotive magneto-rheological brake has been studied by Kerem et al [1]. He investigate the functional structure criteria for fundamental automotive MR brake design. To study the developing magnetic circuit and heat generation in MR brake arrangement using FEM analysis is done. The investigation is made to conclude how changes in the shape of the disc influences the most extreme braking torque instigates inside the brake. MR brake based haptic device has studied by Liu et al. The MR device is possessed of a rotational shaft, plate, MR fluids, an electromagnetic coil and outer casing. The Bingham plastic model is used to derive the equation for transmitted torque [2]. The world largest MR damper maker has given data of magneto-rheological fluid innovation, applications in braking mechanism and properties of magneto-rheological materials. [3].

The MR fluid is made by mixing the micron-sized magnetically particles in suspension in the carrier fluid, that shows rheological properties when come under the influence of external field. The transformation of the MR fluid from free streaming fluid state to a strong like state is reversible and is subject to the magnetic field. John et al gives basic concept of electromagnetism and its application. It also gives insight to the basics of magnetic reluctance and various relations needed for theoretical calculations [4]. Mostly used iron powder which is having high saturation magnetization. These iron particles organize themselves to frame extremely solid chains of "fluxes", while attracting opposite poles as shown in fig. 1.

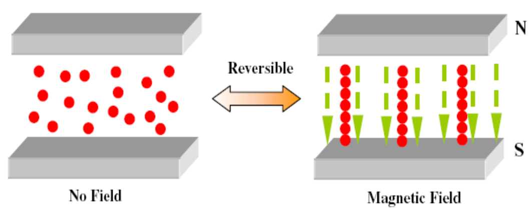
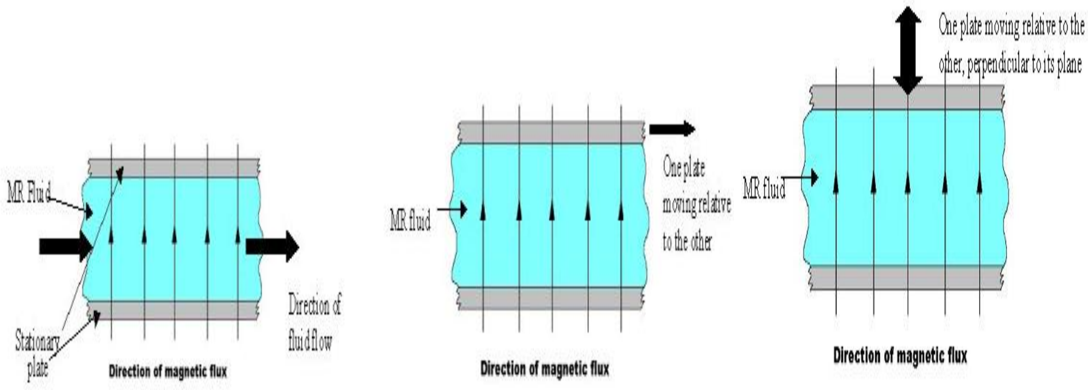


Fig. no.1 MR fluids shows chain-like formation of particles along the direction of an applied magnetic field.

Basically MR fluid is composed of three components basic fluids which is also called as carrier fluid, metal particles and stabilizing additives to avoid corrosion. The base fluid serves as a carrier for the metal particles and normally consolidates its lubrication and damping features. For the MR liquid to have high immersion point the thickness of the liquid ought to be little and be practically autonomous of temperature. During the off state condition, the MR fluids just act as a base fluid depending upon its chemical compositions.

MR fluids can be worked in three modes relying upon the sort of distortion experienced, for example, shear, valve and squeeze mode. While in shear mode, MR fluid situated among moving in connection to one another with the magnetic field streaming oppositely to the bearing of movement of these shear surfaces as shown in the fig. no. 2 (a). The MR fluid is compelled to stream straight forwardly between statics plate in the Valve mode as shown in fig. no.2 (b). Whereas in the squeeze mode, the normal pressure is experience by MR fluid in the direction of magnetic field produced as shown in fig. no.2 (c).



(a) (b) (c)

Fig. no.2 (a) Basic concept of valve mode (b)Basic concept of shear mode (c)Basic concept of squeeze mode

According to the fig. no.3 MR disc brake which illustrate as a 2-D axis symmetric model. Disc is the rotating element while the MR fluid gap & the outer casing are the stationary components in disc brake. The coil which provides magnetic circuit completes the system. The coil of different windings gives the magnetic flux which is vital for stimulating the MR fluid. The current flow through the circuit will be fluctuated to bring variation in the magnetic flux density and in this way the degree to which the MR fluid is energized. A thin lining of plastic is provided in the region of MR fluid clearance and coil side.

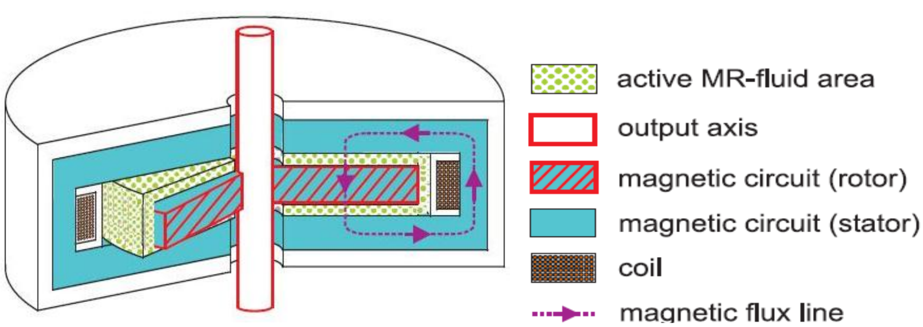


Fig. no.3 Disc type MR Brake

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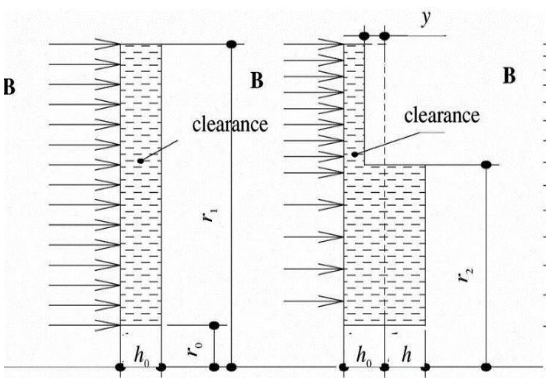
3. Experimentation

The model portrayed is an axisymmetric MR brake that contains four unique zones. The rotating disc represents the first zone, Outer casing is the second, Fluid clearance is third and the fourth is the electrical coil. The applied current to the coil can be change from 0 to 2.0 amperes. In actual, the structure and dimension of the working gap of the brakes can be varying. The fluctuating functional clearance will bring about various magnetic field dispersion and accordingly unique shear yield stress of the Magneto-rheological fluid. Figure 4 shows two pattern of functional gaps. In Fig. 4 (a), the dimension of gap, h, is kept constant in the radial direction; in Fig. 4 (b), shows step-shaped functional gap which is having a step somewhere in radial direction.



(a) (b)

Fig. no.4 Two different working clearance of MR disc brake (a) constant gap, (b) step-shaped gap.

Table no.1 Sizes of different types of working clearances.

Type of clearance	Constant clearance	Step-shaped clearance
Size(mm)	$r_0 = 22; r_1 = 50;$ $h_0 = 1.5$	$r_0 = 22; r_1 = 50;$ $r_2 = 35; y = 0.2$ $h = 0.6$

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3.1 Constant Clearance MR Brake

From the ANSYS model of constant clearance MR disc brake, the magnetic flux density is generated. This flux density will give us the shear stress and subsequently torque induced in the brake.

$$JS = \frac{NI}{A} \qquad (i)$$

Where N is number of coils (= 210), I is current applied, A is electrical coil area (= 165 mm^2) and JS is current density.

Equation (i) shows that the magnetic induction is proportional to the applied current. Therefore, increasing the current would increase the magnetic induction (B).

3.1.1 Magnetic Flux Density for Constant Clearance

Using the ANSYS model, the magnetic field density (B_i) at various nodes in the MR fluid gap is evaluated, Where B_i is the value of magnetic flux density at various nodes at equal radial intervals within the fluid gap. The radial dimension is divided into 8 elements. Each time the electrical current is increased in the coil, it increases the magnetic induction and thus one get a new set of data. For each current value, current density can be given as:

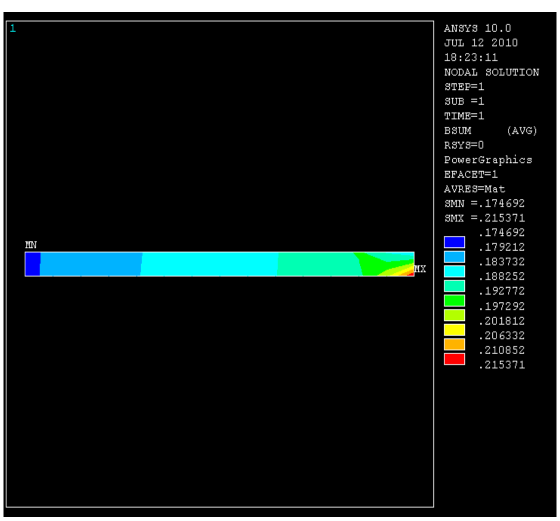

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Fig. no. 5 Magnetic Flux Density for constant clearance model

Table no.2 Magnetic flux density (B) at different nodes for constant working clearance in different current settings.

Node no.	0.2 amp	0.5 amp	0.8 amp	1 amp	1.4 amp	1.8 amp	2 amp
1	0.086	0.215	0.345	0.431	0.603	0.775	0.862
2	0.077	0.191	0.306	0.383	0.536	0.688	0.765
3	0.076	0.187	0.303	0.379	0.530	0.682	0.758
4	0.075	0.185	0.229	0.374	0.524	0.673	0.748
5	0.074	0.184	0.296	0.370	0.518	0.666	0.740
6	0.074	0.182	0.294	0.367	0.514	0.661	0.735
7	0.073	0.182	0.293	0.366	0.512	0.658	0.731
8	0.073	0.181	0.293	0.366	0.512	0.658	0.732

3.1.2 Shear Yield Stress for Constant Clearance

The magnetic induction is dependent on the fluid shear yield stress. The field-dependent maximum stress (τ) is the most critical on-state property of MR-fluids since it directly proportional to the maximum output force or torque of a given device. The magnetic induction-shear yield stress data for a typical MR fluid (shown in Fig. no.6) is characterized by a 4^{th} order polynomial of B_i [5] and is given as,

$$\tau_i = 1150B_i^4 - 2140B_i^3 + 1169B_i^2 - 64B_i + 0.8 \qquad \text{(ii)}$$

Where, τ_i is shear yield stress induce at i^{th} node and B_i is the magnetic flux density (given in Table 3) at i^{th} node.

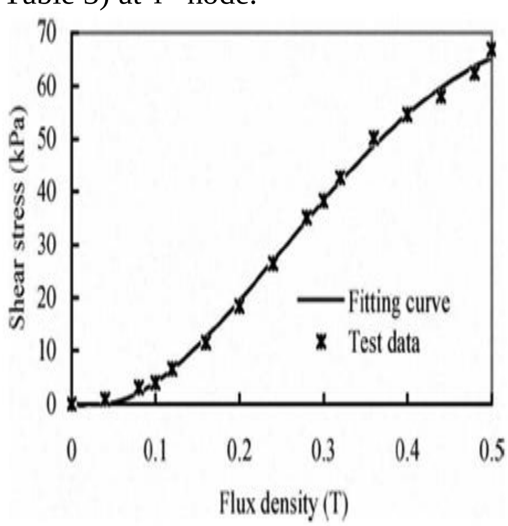

Fig. no. 6 Shear stress Vs magnetic flux density

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Now using the results of magnetic field induce for 7 different currents setting, (as shown in first row of Table 2), calculations are made to find the values of shear stress at all the nodes by using the Eq. no. (ii) and these are shown in Table no. 3.

Table no.3 Shear yield stress (τ) at different nodes for constant working clearance in the different current setting.

Node no.	0.2 amp	0.5 amp	0.8 amp	1 amp	1.4 amp	1.8 amp	2 amp
1	2.66	22.34	46.21	58.69	68.10	72.07	78.44
2	1.83	17.85	39.44	52.20	67.70	70.86	71.76
3	1.77	17.03	38.91	51.67	67.42	70.83	71.58
4	1.69	16.70	38.20	50.93	67.02	70.80	71.38
5	1.64	16.50	37.63	50.33	66.69	70.77	71.25
6	1.59	16.30	37.21	49.89	66.43	70.75	71.18
7	1.57	16.21	36.97	49.64	66.28	70.74	71.14
8	1.57	16.01	36.97	49.64	66.28	70.74	71.14

3.1.3 Torque Induced For Constant Clearance

The magnetic particles are filled inside the constant working clearance of MR brake. It experiences the relative rotation of the rotating disc to the housings and thus produces braking torque under the action of electro-magnetic field.

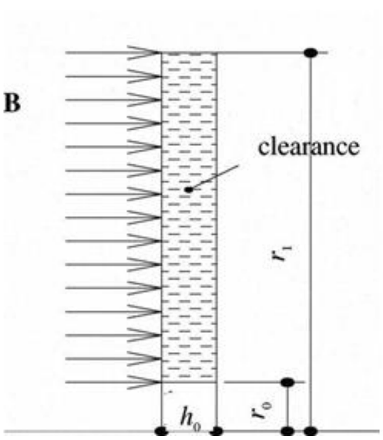

Fig. no. 7 Fluid gap for constant clearance

In Fig. no. 7, r_o is inner radius of rotating disc, r_1 is outer radius of rotating disc and h_o is MR fluid gap. For the model as shown in above Fig., if the MRF distributed at different location in

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the working clearance have the same value of the shear yield stress, τ_b , then the magneto induced torque of the model can be established as [6]

$$T = \underbrace{\frac{4\pi\tau_b}{3}(r_1^3 - r_0^3)}_{\text{non viscous torque}} + \underbrace{\frac{\pi\eta\omega}{h}(r_1^4 - r_0^4)}_{\text{viscous torque}} \qquad \text{(iii)}$$

where, T is the total magneto induced torque of the brake, ω is the angular speed of the rotating disc, η is coefficient of viscosity, h_o is the width of the functional clearance. In the Eq. no. (iii), the first term represents the governable magneto-induced braking torque which is dependent on the variable shear yield stress, τ_b. The τ_b is yield shear stress at particular flux density. The second term represents the constant viscous torque.The variation in magnetic field does not affect the viscous torque and so can be neglected from eq.no.(iii) So the Eq.no. (iii) reduces to

$$T = \frac{4\pi\tau_b}{3}(r_1^3 - r_0^3) \qquad \text{(iv)}$$

Now using the results of magnetic field induce and the shear stress, the torque induced is calculated using Eq. no. (iv) at all those nodes at 7 different currents settings and is shown in Table 4.

Table no.4 Torque induced at different nodes for constant working clearance at different current setting.

Node no.	0.2 amp	0.5 amp	0.8 amp	1 amp	1.4 amp	1.8 amp	2 amp
1	0.16	1.35	2.79	3.54	4.02	4.35	4.73
2	0.09	0.91	2.01	2.66	3.44	3.61	3.65
3	0.08	0.72	1.64	2.18	2.85	2.99	3.02
4	0.06	0.51	1.31	1.75	2.31	2.44	2.46
5	0.05	0.42	1.03	1.38	1.83	1.94	1.95
6	0.03	0.35	0.79	1.05	1.40	1.50	1.50
7	0.03	0.26	0.58	0.78	1.04	1.11	1.12
8	0.02	0.21	0.49	0.66	0.88	0.94	0.95

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3.2 Step-Shape Clearance MR Brake

From the ANSYS model of step-shape clearance MR disc brake, the magnetic flux density is generated and is shown in Fig. no.8. This flux density will give us the shear stress and subsequently torque induced in the brake.

3.2.1 Magnetic Flux Density for Step-Shape Clearance

Using the ANSYS model, the magnetic field density (B_i) at various nodes in the MR fluid gap is evaluated. The results for 7 different currents setting at all 7 elements are shown in Table 5.

3.2.2 Shear Yield Stress for Step-Shape Clearance

The magnetic induction shear yield stress data for a typical MR fluid is shown in Fig.no. 6. It is characterized by a 4^{th} order polynomial of B_i and is given in Eq. no. (ii). Now using the result of magnetic field induce for 7 different currents setting (as shown in first row of Table 5), are made

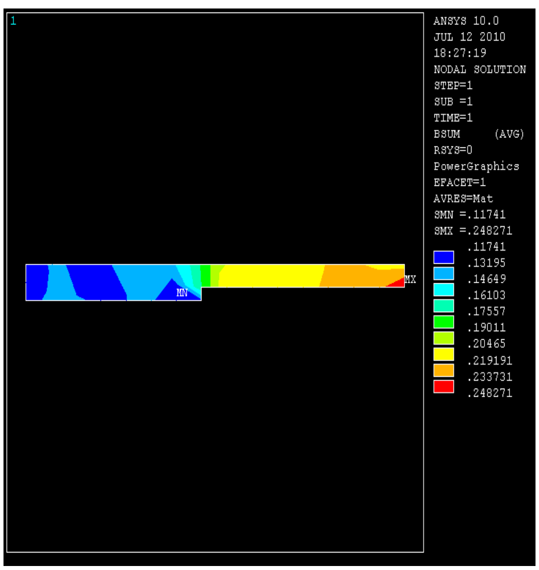

Fig. no. 8 Magnetic Flux Density for step-shape clearance model

Table no. 5 Magnetic flux density at different nodes for step-shape working clearance in different current settings

Node no.	0.2 amp	0.5 amp	0.8 amp	1 amp	1.4 amp	1.8 amp	2 amp
1	0.10	0.25	0.40	0.50	0.70	0.89	0.99
2	0.09	0.22	0.35	0.44	0.62	0.79	0.88
3	0.09	0.21	0.35	0.44	0.61	0.79	0.87
4	0.05	0.14	0.20	0.25	0.36	0.48	0.52
5	0.05	0.13	0.20	0.25	0.34	0.44	0.49
6	0.05	0.13	0.22	0.27	0.38	0.48	0.54
7	0.05	0.13	0.21	0.26	0.37	0.48	0.53
8	0.05	0.13	0.21	0.26	0.37	0.48	0.53

Table no.6 Shear yield stress (τ) at different nodes for step-shape working clearance in the different current setting

Node no.	0.2 amp	0.5 amp	0.8 amp	1 amp	1.4 amp	1.8 amp	2 amp
1	3.99	28.59	54.33	65.16	70.88	83.38	112.74
2	2.82	23.15	47.35	59.69	70.32	72.67	80.85
3	2.76	20.98	46.97	59.36	70.25	72.45	79.99
4	0.31	9.03	19.39	29.23	49.42	63.53	67.00
5	0.23	8.13	18.88	28.14	46.15	60.06	64.79
6	0.41	8.17	22.21	32.42	51.19	64.06	67.76
7	0.37	8.10	21.50	31.53	50.18	63.31	67.24
8	0.38	8.09	21.57	31.61	50.27	63.39	67.29

calculations to find the values of shear stress at all the nodes by using the Eq. no. (ii) and these are shown in Table no.6.

3.3.3 Torque Induced For Step-Shape Clearance

The basic design of the rotary MRF disc brake is shown in Fig. no.3. The rotating disc experience relative rotation during electromagnetic field is on and thus produces braking torque.

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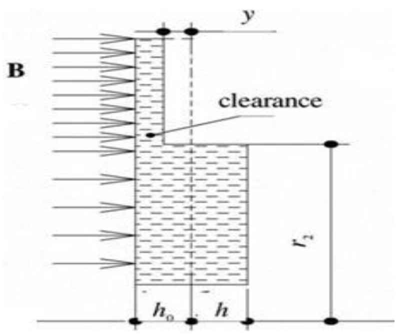

Fig.no. 9 MR Fluid gap for step-shape clearance

In Fig.no.9, h_o is MR fluid gap in constant clearance, $h_0 + h$ is MR fluid gap in shaft side, $h_0 - y$ is MR fluid gap in coil side and r_2 is radius at step. Now using the results of magnetic field induce (Table 5) and the shear stress (Table 6), the torque induced is calculated using Eq. no. (iv) at all those nodes at 7 different currents setting and is shown in Table 7.

Table no. 7 Torque induced at different nodes for step-shape working clearance at different current setting

Node no.	0.2 amp	0.5 amp	0.8 amp	1 amp	1.4 amp	1.8 amp	2 amp
1	0.24	1.72	3.28	3.93	4.28	5.03	6.80
2	0.14	1.19	2.41	3.04	3.58	3.70	4.11
3	0.12	0.89	1.98	2.51	2.97	3.06	3.38
4	0.01	0.43	0.71	1.11	1.69	2.17	2.33
5	0.01	0.33	0.52	0.77	1.26	1.64	1.77
6	0.01	0.17	0.47	0.69	1.08	1.35	1.43
7	0.01	0.13	0.34	0.50	0.79	1.00	1.06
8	0.01	0.13	0.34	0.50	0.79	1.00	1.06

4. Results and discussion

To ascertain the validity of the ANSYS results, these have been compared with the experimental results available in the literature [6], which are evaluated only at 0.5 amp current. For the two types MRF disc brakes, the magnetic flux density at current 0.5 amp at all 7 nodes is shown in Table no. 8. The data is plotted in Fig.no.10.

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Table no.8 Comparison of magnetic flux density of both configurations at 0.5amp

Radius (mm)	Constant Clearance	Step Shape Clearance
24	0.181	0.132
28	0.182	0.132
32	0.183	0.132
36	0.184	0.134
40	0.186	0.201
44	0.189	0.218
48	0.201	0.230
50	0.215	0.248

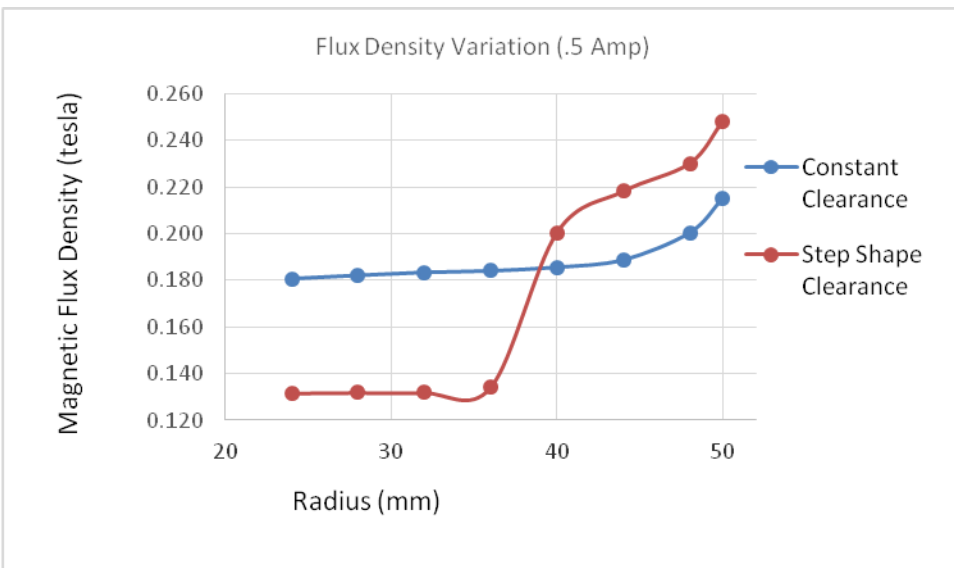

Fig. no.10 Magnetic flux density at0 .5 amp current in two MRF brake models

For the two types MRF disc brakes, the shear yield stress at current 0.5 amp at all 7 nodes is shown in Table no. 9. The data is plotted in Fig.no.11.

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Table no.9 Comparison of Shear yield stress of both configurations at 0.5amp

Radius (mm)	Constant Clearance	Step Shape Clearance
24	16.010	8.093
28	16.262	8.126
32	16.483	8.124
36	16.599	8.462
40	16.876	20.279
44	17.450	22.870
48	19.574	25.135
50	22.336	28.587

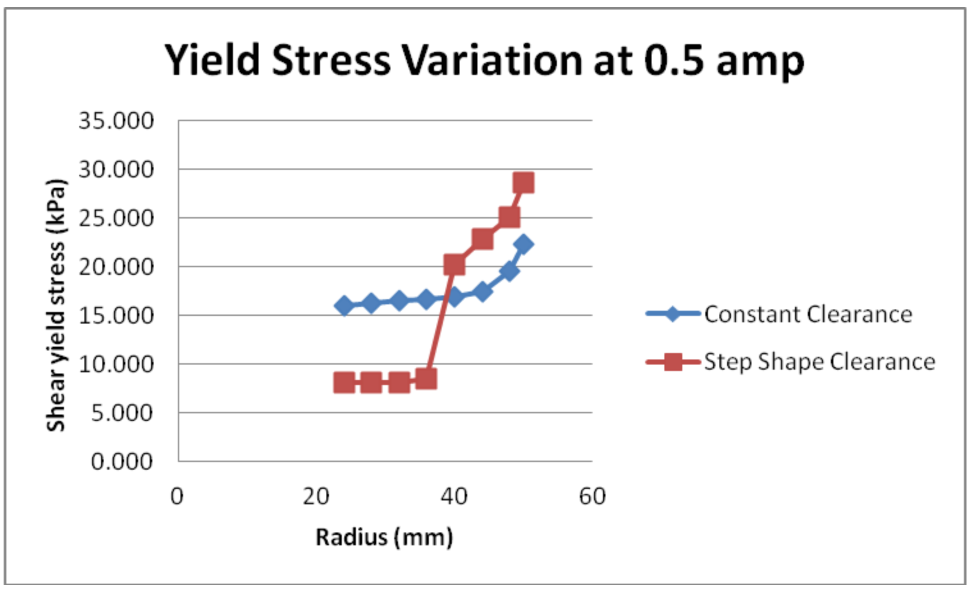

Fig. no.10 Shear yield stress at 0 .5 amp current in two MRF brake models

At last for the two types MRF disc brakes, the torque transmitted at current 0.5 amp at all 7 nodes is shown in Table no. 10. The data is plotted in Fig.no.12. As seen in fig. no.10 the value of shear stress is increasing rapidly with the increase in radius. The value of torque is increasing as compare to constant functional gap with step shaped working clearance.

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Table no.10 Comparison of torque transmitted in both configurations at 0.5amp

Radius (mm)	Constant Clearance	Step Shape Clearance
24	0.213	0.127
28	0.288	0.149
32	0.378	0.203
36	0.451	0.393
40	0.615	0.651
44	0.811	1.074
48	1.036	1.317
50	1.347	1.724

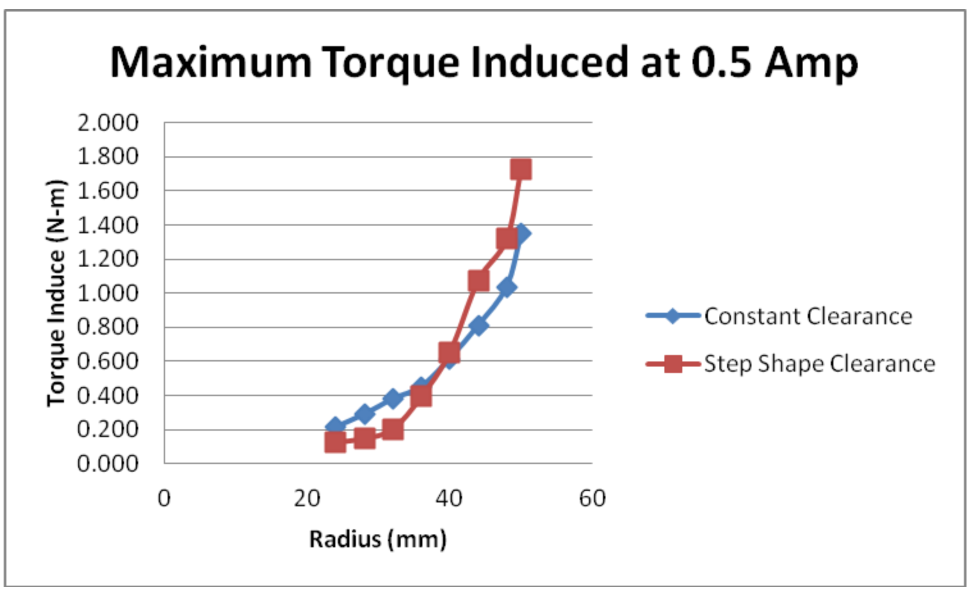

Fig. no.11 Torque transmitted at 0 .5 amp current in two MRF brake models

5. CONCLUSION

Results show that the basic structure and dimension of the functional gap on revolving MRF brake has huge effect upon density of dispersion magnetic flux. So as to accomplish more noteworthy magneto-induced braking torque yield, the basic structure and dimension ought to sensibly intend to change so that induced magnetic effect focus nearer to the external edge of the rotating wheel.

Results show that under the excitation current produced magnetic flux induced on the functional gap stay unaltered; the output of step-shaped is better than that of the constant functional gap brake. Under the conditions given in this paper, the produced magneto braking torques of step shape are increased by 7% relative to the magneto-induced braking torque of the brake with a constant clearance.

6. References

1. Kerem Karakoc, Edward J. Park and Afzal Suleman, "Design considerations for automotive magneto-rheological brake", Journal of mechatronics 2008.

2. B Liu, WH Li1, P B Kosasih and X Z Zhang, "Development of an MR-brake-based haptic device", Journal of Smart Mater. Struct. 15 (2006) 1960–1966.

3. http://www.lord.com/Portals/0/MR/Commercial_MR_Fluid_Devices.pdf.

4. John D. Kraus, "Electromagnetics" 6th Edition, Mc-Graw-Hill Inc., Singapore, 2006.

5. Zheng Di, "optimal design for working clearance of MR damper", Proceedings of the 2009 IEEE, international conference on mechatronics and automation, august 9-12, China.

6. More Thomas, "MR-fluid brake design and its application to a portable muscular rehabilitation device", Doctor of Philosophy thesis, Department of Mechanical Engineering and Robotics, November 2009.

