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Application of Magneto-Rheological Fluid in Bearings

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Abstract

Bearings are vital mechanical devices that support rotating elements and come in various shapes and sizes. To enhance their performance, modern lubrication methods using MR fluids and a permanent magnet for consistent magnetic fields are proposed. This approach aims to reduce friction, increase efficiency, extend lifespan, and ensure pressure-tight operation. However, the design currently struggles with high radial loads. Further research is needed to explore different carrier fluids, suspended particles, and magnetic material interactions. If perfected, this new method could significantly improve modern machine tools, although additional efforts are required for industrial applications.

I: BEARING

1.1 Bearing

Bearings are essential machine components that restrict motion to desired paths while reducing friction between moving parts. They enable smooth movement in vehicles, household appliances, and industrial machinery by minimizing wear and tear and facilitating efficient performance. Bearings are classified based on their operational function, permissible movements, and load directions. They play a pivotal role in automobiles, machinery, and even satellites, ensuring stability and energy efficiency despite operating in harsh, unseen environments. Their silent, robust functionality is indispensable for maintaining high performance across various applications.

1.2 Classification of Bearing

a. According to direction of load
   i. Radial Bearing
   ii. Thrust Bearing
b. According to type of contact
   i. Sliding contact bearing
   ii. Rolling contact bearing

1.3.1 Rolling (Ball bearing) bearing:

1.3 Ball Bearing

Rolling bearings consist of an outer ring, inner ring, rolling elements (balls or rollers), and a cage to hold the rolling elements in place. This simple structure allows for smooth rotational movement.

1.4 Types of ball bearing

1.4.1. Deep Grove ball bearing
1.4.2. Angular contact thrust ball bearing
1.4.3. Thrust Ball bearing
1.4.4. Self-aligning roller bearing
1.4.5. Cylindrical rolling bearing
1.4.6. Cylindrical roller bearing
1.4.7. Tapered roller bearing
1.4.8. Thrust needle bearing
1.4.9. Cage and Roller

1.5 Limitations

As a result, journal bearings have a high load capacity, and the root cause of high friction is known. And although roller bearings are built on the sliding principle and carry less load than the journal equivalent of identical size, tolerances are much lower. While high load, high-speed bearings are expensive, the following high-RPM operation occasionally boosts maintenance costs. Furthermore, they need sophisticated tools for precision installation. High-precision purpose-built bearings are less versatile.

II: SMART FLUIDS

2.1 INTRODUCTION TO FIELD SENSITIVE FLUIDS:

Smart materials possess properties that can be adjusted through external fields, like ferro-electricity, pyro-electricity, piezoelectricity, and more. These materials are usually solid, such as polycrystalline forms, bulk materials, or thin films on substrates. Additionally, there are 'field responsive fluids such as magneto-rheological fluids, ferrofluids, electro-rheological fluids, and certain polymeric gels, which respond to external fields.

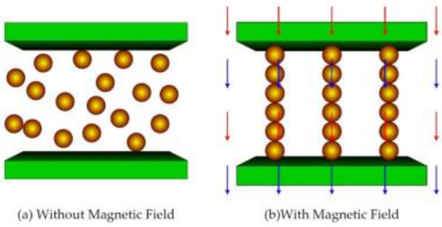


Fig 2.2: MR Fluid Behaviour

2.2 MAGNETO RHEOLOGICAL FLUIDS:

MR fluids are dispersions of ferromagnetic or ferrimagnetic particles in an organic or aqueous carrier, commonly using high purity iron powder. In their 'off' state, they resemble liquid paints with low viscosity. When exposed to a magnetic field, the particles become magnetized, align, and form structures that significantly increase yield stress, which can reach up to 100 kPa. The response time of MR fluids is around 10-20 milliseconds. MR fluids are reversible and find applications in active vibration control, automotive dampers, and torque transfer. Their properties are influenced by composition, magnetic field strength, and the design of the magnetic circuit.

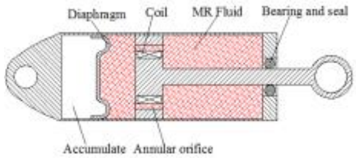


FIG 2.3 MR Damper

2.3 APPLICATION IN DAMPING

MRF dampers can adjust their damping in real-time based on external vibrations, making them valuable in engineering. They work by generating a magnetic field through a coil, which acts on the magneto-rheological fluid in circular damp channels, causing the piston to move and change the fluid's motion characteristics. This adjustment alters the pressure difference between chambers, controlling the damping force. Universities like Maryland and Nevada have developed various MRF dampers for different applications, such as artillery recoil devices and automotive shock absorbers. These designs include double-piston, double-rod shear valve, and rotary shear MR dampers.

2.4 APPLICATION IN TRANSMISSION

Magneto-rheological (MR) transmission technology, developed in the 1990s, uses the rheological effect of MR fluids as the transmission medium. A magnetic field, generated by a coil, adjusts the fluid's shear yield stress, thereby changing the transmission torque and force. Researchers have extensively studied MR fluid transmission devices, such as the cylindrical actuator by Chongqing University and the small power actuator by China University of Mining Technology. Applications include automotive MR brakes designed by Northeast Forestry University, which meet the braking torque needs of small cars.

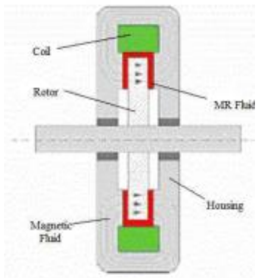


FIG 2.4 MR TRANSMISSION

2.5 APPLICATION IN OTHER FIELDS

MRF Sealing Device

Kordonsky's experiments on single-stage sealing with magneto-rheological fluid (MRF) show that adjusting MRF viscosity in the sealing gap provides effective sealing, with benefits like simple structure and minimal maintenance. Fujita further analyzed how particle size, shape, and carrier liquid viscosity affects torque and pressure. Li Jingsong's team developed a low-friction, long-lasting MRF seal ring.

MRF Composite Component

In mechanical systems, MRF can be used in composite components like plates, discs, and beams to adjust stiffness and damping by altering shear and compression/tensile modulus. Weiss and Carlson have patented several MRF composite components for vibration control and other applications.

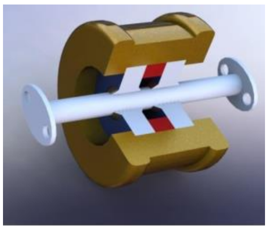
MRF Flexible Fixture

MRF flexible fixtures are designed to handle small or irregularly shaped parts during manufacturing. Tang's research demonstrated that MRF's rapid phase transition and high yield strength help improve accuracy and reduce processing time.

III:CONCEPT OF MAGNETORHEOLOGICAL FLUID BEARING

3.1 CONCEPT DESCRIPTION

This research aims to create a bearing with no solid contact between moving parts to reduce frictional losses. It uses a magnetic field to suspend a magnetizable shaft, with MR fluid that behaves like a solid with high shear strength when magnetized, supporting axial or radial loads. A magnetic flux loop, formed by magnetizable collars and a permanent magnet, aligns MR particles in the gap, providing the necessary load capacity. The Ferro particles are micrometer-sized for optimal performance.



FI: 3.1 CONCEPT OF BEARING

3.2 Material Selection

The selection of materials is crucial for the proper functioning of the bearing. The key components include:

- Magnet: Neodymium magnets (NdFeB 40) are chosen for their strong magnetic field to hold Ferro particles.
- Collar material: 1006 steel is used for collars due to its magnetizability and ability to support heavy radial loads.
- Housing material: Either 304 stainless steel or 1006 aluminum alloy, both non-magnetizable, are suitable for their strength and cost-effectiveness.
- Shaft material: 1006 steel is selected for its high magnetizability and mechanical strength to transmit torque during testing.

In essence, each material is chosen for its specific properties to ensure the bearing performs efficiently.

IV: SIMULATION AND RESULTS

4.1 SIMULATION

The FEMM simulations were vital in refining the physical dimensions of the bearing components from conceptual design to the actual prototype. After finalizing the concept, several iterations of FEMM simulations helped identify patterns to achieve the final dimensions.

1. Magnet Dimensions: The initial focus was on finding the relationship between different dimensions of identical material magnets, leading to finalized dimensions and simplified further simulations.

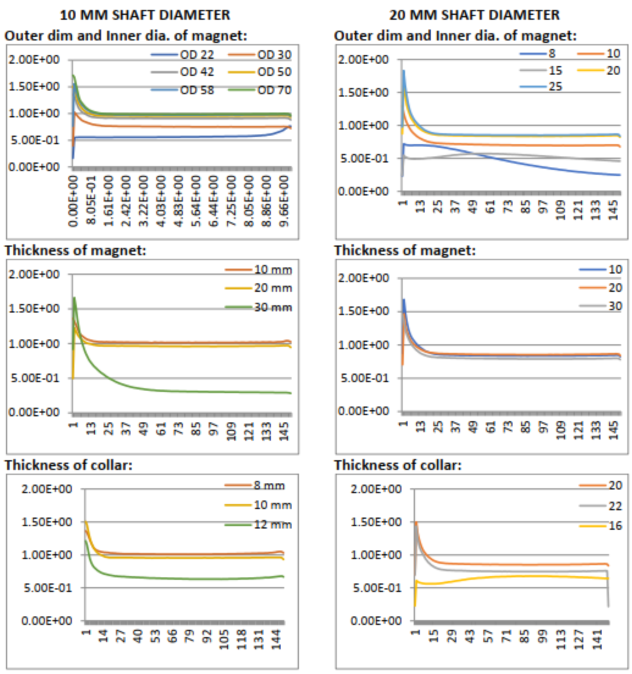
2. Collar Thickness: The thickness of magnetizable collars was adjusted to ensure maximum flux development at the gap where MR fluid would be filled.

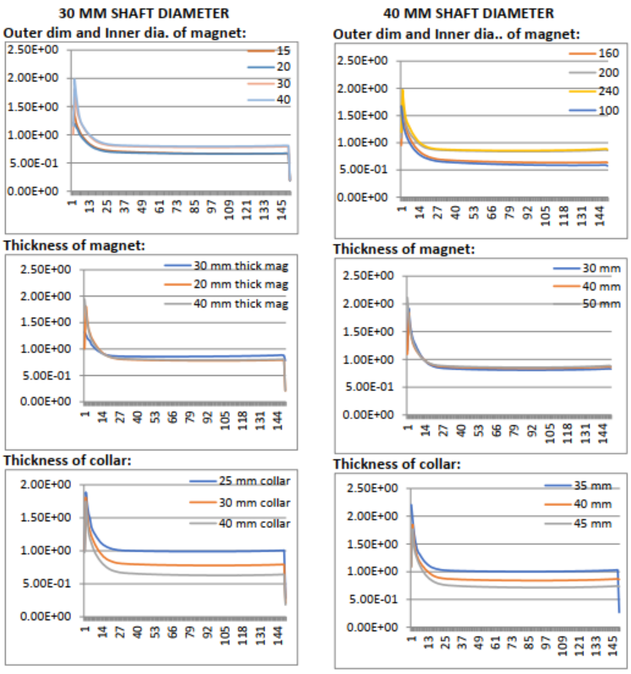
3. Housing and Shaft Assembly: With the major components ready, the housing and shaft were designed for easy assembly and manufacturing, including a housing design with 4 M6 bolts for stability during operation.

In essence, the iterative FEMM simulations played a crucial role in determining the final dimensions and ensuring the effective assembly and operation of the bearing.

To analyze the flux line behavior in a system, the FEMM analysis setup involves specifying materials and varying dimensions to observe patterns. The process starts with creating a 2-D representation of a 3-D axis-symmetrical problem, selecting material properties from the software's library, and meshing the setup to the required density. Once meshing is complete, the software calculates the effects of the dimensions on flux line behavior, providing values for flux density, field intensity, and current density along the flux lines' distribution.

4.2 SIMULATION RESULTS

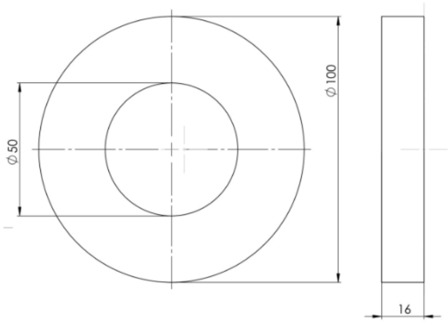




V: MANUFACTURING

5.1 CAD DRAWINGS

The final design dimensions were mechanically and structurally robust, making them ready for manufacturing, with detailed CAD drawings prepared for each part and the assembly which are as below:



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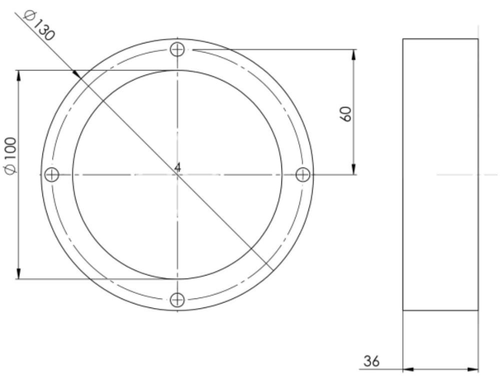

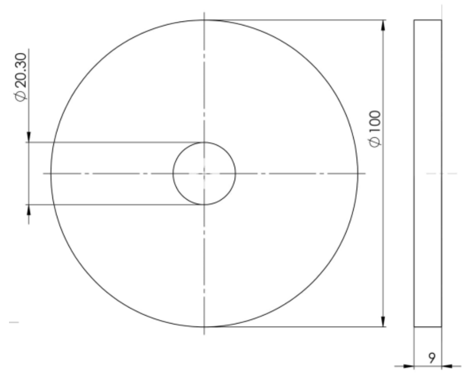

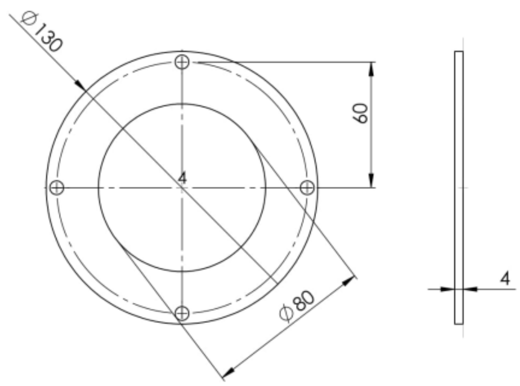

5.2 Manufactured Parts

The CAD drawings facilitated the manufacturing of parts with high accuracy, aligning with the proposed design. While most parts, such as housing, lids, and collar faces, were made on a center lathe, the boring of the collar and shaft turning were executed on a CNC lathe. This ensured an extremely smooth finish with tight tolerances, creating a small gap to build up sufficient field intensity for generating a thin, strong lubricant film around the shaft.

VI: TESTING PROCEDURE

The testing phase is crucial for validating the research efforts and evaluating the performance of the proposed all-purpose anti-friction bearing design. The prototype was tested by mounting it on a spindle delivering a constant 240 rpm for 16 minutes. The presence of friction was assessed by examining surface scratches or signs of wear on the shaft and collars. Surface roughness plots were taken to distinguish machining scratches from friction scratches. Results indicated that the MR fluid effectively reduces friction, as evidenced by smooth shaft rotation and low noise levels, suggesting proper shaft support by the fluid film. However, under radial loading, the fluid's compressive strength was insufficient, resulting in surface scratches due to the lack of viscous strength and homogeneous carrier fluid. This highlights the limitations of the MR fluid in certain conditions.

FIG 6.1: TESTING

VII: CONCLUSION

The results highlight the effectiveness of MR fluid in reducing friction at interacting surfaces but also reveal its inability to withstand radial forces due to insufficient viscous shearing and compressive rigidity. While research has well-documented the relationship between field intensity and yield strength, the link between compressive strength and field intensity is more complex. To develop an all-purpose bearing, further research is needed to vary the properties of MR fluid constituents, focusing on particle size and carrier fluid viscosity. Successful samples should undergo extensive testing to create a comprehensive catalog, aiding in the selection of the appropriate fluid for specific applications.

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Measured Result

Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value
Roughness 2D<SurfAnalysis_1>		Ry	16.1957um	Rt3	17.3723um	Rt	20.9624um		
Profile=R - Section=[1]		Rt1	12.6269um	Rt4	20.1514um	Rz	12.6789um		
Ra	2.2163um	Rt2	15.7066um	Rt5	15.1215um	da	5.8152degree		

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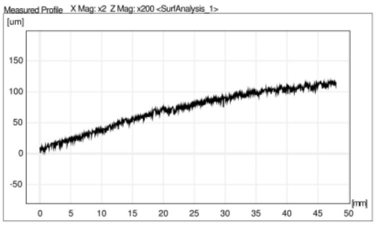

Evaluation Condition

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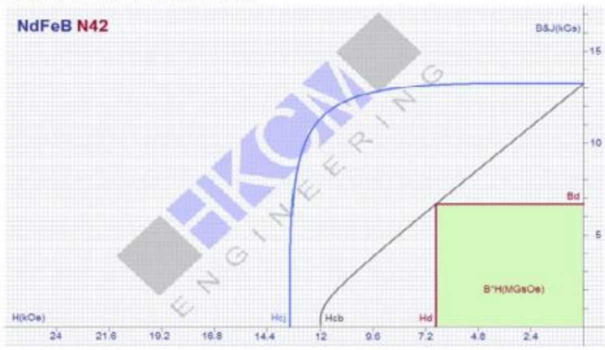
Standard	OLDMIX	Kind of Filter:	Gaussian	Mean Line Compensation	On
Kind of Profile:	R	Evltn Length(lm):	40.0mm	Compensation:	R-Curve(Auto) All
Smplg Length(le):	8.0mm	Pre-Travel:	4.0mm		
No of Smplg(nle):	5	Post-Travel:	3.985mm		

BH-diagram (de-magnetisation curve)



ENERGY PRODUCT = Hd*Bd = 42 Mega Gauss * Oersted (MGO)

Grade	N42	
Residual Induction Br	12.8-13.2 (1280-1320)	KC (mT)
Coercive Force Hcb	11.5 (915)	kOe(KA/m)
Intrinsic Coercive Force Hci	12.0 (955)	kOe(KA/m)
Energy Product BHmax	40-43 (318-342)	MGO(KJ/m3)
Max. Operating Temp.	00	°C

PROPERTIES OF MAGNET

APPENDEX

Material Selection Table

PERMANENT MAGNETS:

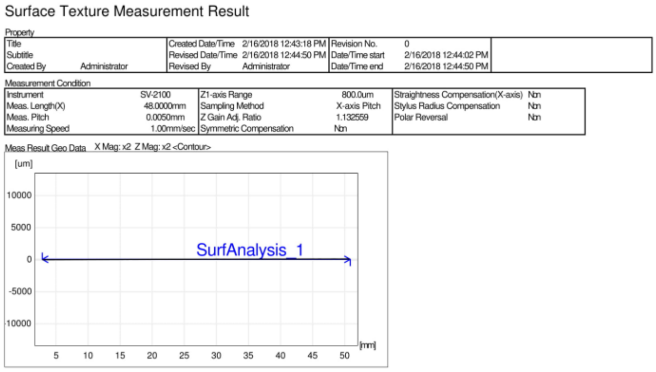
1. Alnico magnets
2. NdFeB magnets
3. Ceramic magnets
4. SmCo magnets

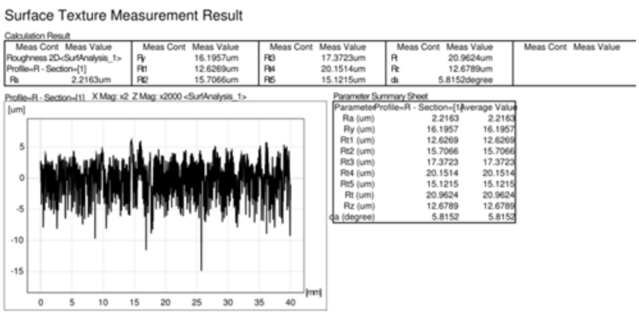
MAGNETISABLE MATERIALS:

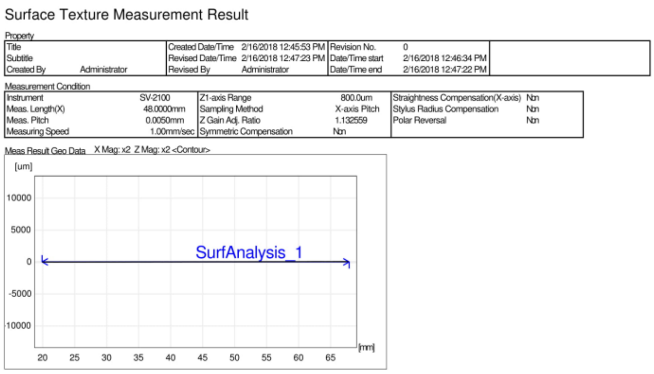
1. 1006 Steel	8. 455 Stainless Steels
2. 1010 steel	9. M-15 Steel
3. 1018 steel	10. M-19 Steel
4. 1020 steel	11. M-22 Steel
5. 1117 steel	12. M-27 Steel
6. 416 Stainless steels	13. M-43 Steel
7. 430 Stainless steels	14. M-47 Steel

NON-MAGNETISABLE MATERIALS:

1. titanium	4. copper
2. 316 Stainless Steel	5. Aluminum 6061-T6
3. 304 Stainless Steel	6. Aluminum 1100







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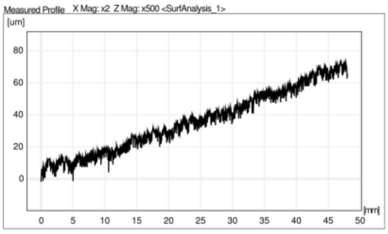
Ra	2.2067um	Rt2	13.3164um	Rt5	13.3190um	da	5.7835degree		

Measured Profile X Mag: x2 Z Mag: x500 <SurfAnalysis_1>



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Smplg Length(le):	8.0mm	Pre-Travel:	4.0mm		
No of Smplg(nle):	5	Post-Travel:	3.995mm		

Surface Texture Measurement Result

Calculation Result

Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value
Roughness 2D<SurfAnalysis_1>		Ry	13.9289um	Rt3	12.5566um	Rt	17.4990um		
Profile=R - Section=[1]		Rt1	17.1730um	Rt4	13.2795um	Rz	12.0338um		
Ra	2.2067um	Rt2	13.3164um	Rt5	13.3190um	da	5.7835degree		

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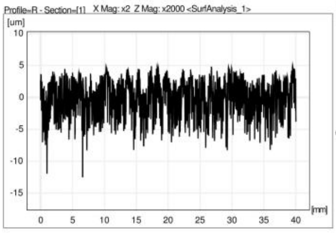

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Ry (um)	13.9289	13.9289
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Rt2 (um)	13.3164	13.3164
Rt3 (um)	12.5566	12.5566
Rt4 (um)	13.2795	13.2795
Rt5 (um)	13.3190	13.3190
Rt (um)	17.4990	17.4990
Rz (um)	12.0338	12.0338
da (degree)	5.7835	5.7835

Surface Texture Measurement Result

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Subtitle		Revised Date/Time	2/16/2018 12:52:22 PM	Date/Time start	2/16/2018 12:51:33 PM
Created By	Administrator	Revised By	Administrator	Date/Time end	2/16/2018 12:52:21 PM

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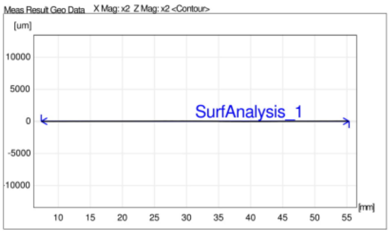

Measured Result

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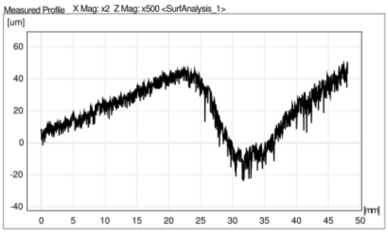

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Smplg Length(le):	8.0mm	Pre-Travel:	4.0mm		
No of Smplg(nle):	5	Post-Travel:	3.995mm		

Surface Texture Measurement Result

Calculation Result

Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value
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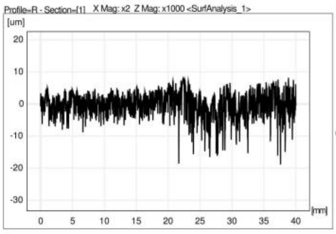

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Rt3 (um)	26.6937	26.6937
Rt4 (um)	23.2974	23.2974
Rt5 (um)	27.1900	27.1900
Rt (um)	27.1900	27.1900
Rz (um)	17.8351	17.8351
da (degree)	7.8470	7.8470

Surface Texture Measurement Result

Property

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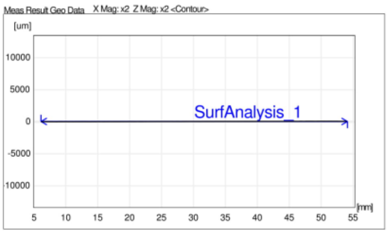
Meas. Pitch	0.0050mm	Z Gain Adj. Ratio	1.132559	Polar Reversal	Ncn
Measuring Speed	1.00mm/sec	Symmetric Compensation	Ncn		

Meas Result Geo Data X Mag: x2 Z Mag: x2 <Contour>



Measured Result

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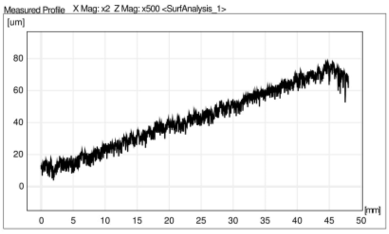
Profile=R - Section=[1]		Rt1	13.1003um	Rt4	13.7959um	Rz	12.2114um		
Ra	2.1214um	Rt2	14.0109um	Rt5	13.6329um	da	6.2672degree		

Measured Profile X Mag: x2 Z Mag: x500 <SurfAnalysis_1>



Evaluation Condition

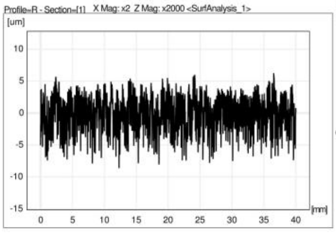
Profile=R - Section=[1]		Lc	8.0mm	Smooth Connection	Of
Standard	OLDMIX	Kind of Filter:	Gaussian	Mean Line Compensation	On
Kind of Profile:	R	Evltn Length(lm):	40.0mm	Compensation:	R-Curve(Auto) All
Smplg Length(le):	8.0mm	Pre-Travel:	4.0mm		
No of Smplg(nle):	5	Post-Travel:	4.0mm		

Surface Texture Measurement Result

Calculation Result

Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value
Roughness 2D<SurfAnalysis_1>		Ry	13.6966um	Rt3	13.9431um	Rt	14.7981um		
Profile=R - Section=[1]		Rt1	13.1003um	Rt4	13.7959um	Rz	12.2114um		
Ra	2.1214um	Rt2	14.0109um	Rt5	13.6329um	da	6.2672degree		

Profile=R - Section=[1] X Mag: x2 Z Mag: x2000 <SurfAnalysis_1>



Parameter Summary Sheet

Parameter	Profile=R - Section=[1	Average Value
Ra (um)	2.1214	2.1214
Ry (um)	13.6966	13.6966
Rt1 (um)	13.1003	13.1003
Rt2 (um)	14.0109	14.0109
Rt3 (um)	13.9431	13.9431
Rt4 (um)	13.7959	13.7959
Rt5 (um)	13.6329	13.6329
Rt (um)	14.7981	14.7981
Rz (um)	12.2114	12.2114
da (degree)	6.2672	6.2672

Surface Texture Measurement Result

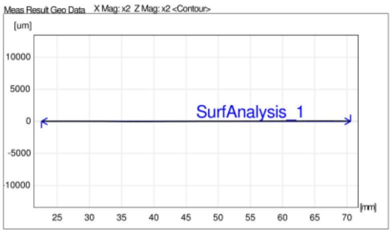
Property

Title		Created Date/Time	2/16/2018 12:54:33 PM	Revision No.	0
Subtitle		Revised Date/Time	2/16/2018 12:56:15 PM	Date/Time start	2/16/2018 12:55:27 PM
Created By	Administrator	Revised By	Administrator	Date/Time end	2/16/2018 12:56:15 PM

Measurement Condition

Instrument	SV-2100	Z1-axis Range	800.0um	Straightness Compensation(X-axis)	Ncn
Meas. Length(X)	48.0000mm	Sampling Method	X-axis Pitch	Stylus Radius Compensation	Ncn
Meas. Pitch	0.0050mm	Z Gain Adj. Ratio	1.132559	Polar Reversal	Ncn
Measuring Speed	1.00mm/sec	Symmetric Compensation	Ncn		

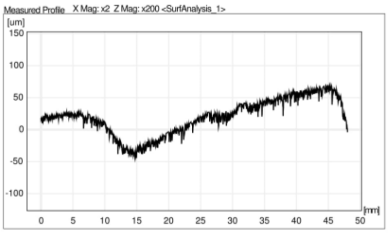
Meas Result Geo Data X Mag: x2 Z Mag: x2 <Contour>



Measured Result

Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value
Roughness 2D<SurfAnalysis_1>		Ry	30.6072um	Rt3	31.1790um	Rt	38.2779um		
Profile=R - Section=[1]		Rt1	28.2224um	Rt4	28.7684um	Rz	23.8909um		
Ra	3.8507um	Rt2	29.4379um	Rt5	35.4281um	da	9.3285degree		

Measured Profile X Mag: x2 Z Mag: x200 <SurfAnalysis_1>



Evaluation Condition

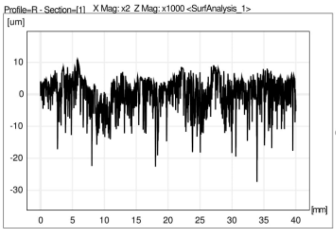
Profile=R - Section=[1]		Lc	8.0mm	Smooth Connection	Off
Standard	OLDMIX	Kind of Filter:	Gaussian	Mean Line Compensation	On
Kind of Profile:	R	Evltn Length(lm):	40.0mm	Compensation:	R-Curve(Auto) All
Smplg Length(le):	8.0mm	Pre-Travel:	4.0mm		
No of Smplg(nle):	5	Post-Travel:	4.0mm		

Surface Texture Measurement Result

Calculation Result

Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value
Roughness 2D<SurfAnalysis_1>		Ry	30.6072um	Rt3	31.1790um	Rt	38.2779um		
Profile=R - Section=[1]		Rt1	28.2224um	Rt4	28.7684um	Rz	23.8909um		
Ra	3.8507um	Rt2	29.4379um	Rt5	35.4281um	da	9.3285degree		

Profile=R - Section=[1] X Mag: x2 Z Mag: x1000 <SurfAnalysis_1>



Parameter Summary Sheet

Parameter	Profile=R - Section=[1]	Average Value
Ra (um)	3.8507	3.8507
Ry (um)	30.6072	30.6072
Rt1 (um)	28.2224	28.2224
Rt2 (um)	29.4379	29.4379
Rt3 (um)	31.1790	31.1790
Rt4 (um)	28.7684	28.7684
Rt5 (um)	35.4281	35.4281
Rt (um)	38.2779	38.2779
Rz (um)	23.8909	23.8909
da (degree)	9.3285	9.3285

Surface Texture Measurement Result

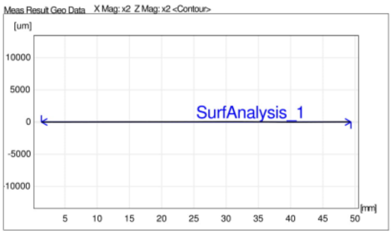
Property

Title		Created Date/Time	2/16/2018 12:56:42 PM	Revision No.	0
Subtitle		Revised Date/Time	2/16/2018 12:58:18 PM	Date/Time start	2/16/2018 12:57:29 PM
Created By	Administrator	Revised By	Administrator	Date/Time end	2/16/2018 12:58:18 PM

Measurement Condition

Instrument	SV-2100	Z1-axis Range	800.0um	Straightness Compensation(X-axis)	Non
Meas. Length(X)	48.0000mm	Sampling Method	X-axis Pitch	Stylus Radius Compensation	Non
Meas. Pitch	0.0050mm	Z Gain Adj. Ratio	1.132559	Polar Reversal	Non
Measuring Speed	1.00mm/sec	Symmetric Compensation	Non		

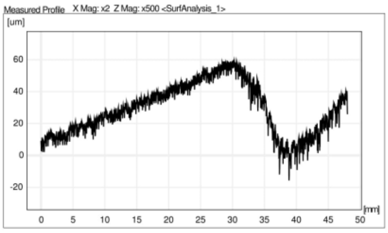
Meas Result Geo Data X Mag: x2 Z Mag: x2 <Contour>



Measured Result

Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value
Roughness 2D<SurfAnalysis_1>		Ry	19.5345um	Rt3	13.1751um	Rt	33.3295um		
Profile=R - Section=[1]		Rt1	15.6000um	Rt4	26.8450um	Rz	16.2968um		
Ra	2.7472um	Rt2	12.8351um	Rt5	29.2170um	da	7.4705degree		

Measured Profile X Mag: x2 Z Mag: x500 <SurfAnalysis_1>



Evaluation Condition

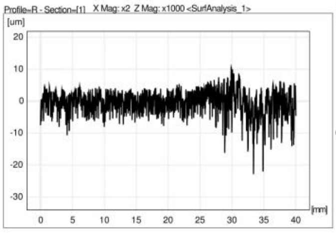
Profile=R - Section=[1]		Lc	8.0mm	Smooth Connection	Off
Standard	OLDMIX	Kind of Filter:	Gaussian	Mean Line Compensation	On
Kind of Profile:	R	Evltn Length(lm):	40.0mm	Compensation:	R-Curve(Auto) All
Smplg Length(le):	8.0mm	Pre-Travel:	4.0mm		
No of Smplg(nle):	5	Post-Travel:	4.0mm		

Surface Texture Measurement Result

Calculation Result

Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value
Roughness 2D<SurfAnalysis_1>		Ry	19.5345um	Rt3	13.1751um	Rt	33.3295um		
Profile=R - Section=[1]		Rt1	15.6000um	Rt4	26.8450um	Rz	16.2968um		
Ra	2.7472um	Rt2	12.8351um	Rt5	29.2170um	da	7.4705degree		

Profile=R - Section=[1] X Mag: x2 Z Mag: x1000 <SurfAnalysis_1>



Parameter Summary Sheet

Parameter	Profile=R - Section=[1]	Average Value
Ra (um)	2.7472	2.7472
Ry (um)	19.5345	19.5345
Rt1 (um)	15.6000	15.6000
Rt2 (um)	12.8351	12.8351
Rt3 (um)	13.1751	13.1751
Rt4 (um)	26.8450	26.8450
Rt5 (um)	29.2170	29.2170
Rt (um)	33.3295	33.3295
Rz (um)	16.2968	16.2968
da (degree)	7.4705	7.4705

Surface Texture Measurement Result

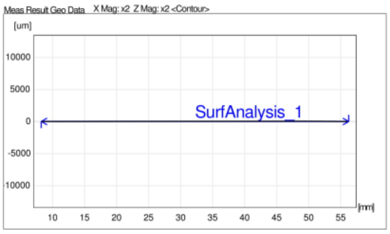
Property

Title		Created Date/Time	2/16/2018 12:58:43 PM	Revision No.	0
Subtitle		Revised Date/Time	2/16/2018 1:00:43 PM	Date/Time start	2/16/2018 12:59:55 PM
Created By	Administrator	Revised By	Administrator	Date/Time end	2/16/2018 1:00:43 PM

Measurement Condition

Instrument	SV-2100	Z1-axis Range	800.0um	Straightness Compensation(X-axis)	Non
Meas. Length(X)	48.0000mm	Sampling Method	X-axis Pitch	Stylus Radius Compensation	Non
Meas. Pitch	0.0050mm	Z Gain Adj. Ratio	1.132559	Polar Reversal	Non
Measuring Speed	1.00mm/sec	Symmetric Compensation	Non		

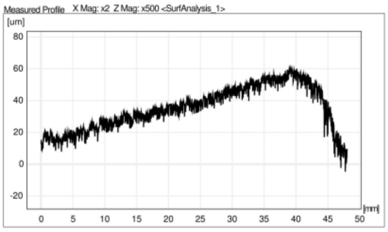
Meas Result Geo Data X Mag: x2 Z Mag: x2 <Contour>



Measured Result

Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value
Roughness 2D<SurfAnalysis_1>		Ry	14.4007um	Rt3	12.3938um	Rt	17.6012um		
Profile=R - Section=[1]		Rt1	15.0077um	Rt4	14.1016um	Rz	12.7035um		
Ra	2.1905um	Rt2	12.9109um	Rt5	17.5896um	da	6.1075degree		

Measured Profile X Mag: x2 Z Mag: x500 <SurfAnalysis_1>



Evaluation Condition

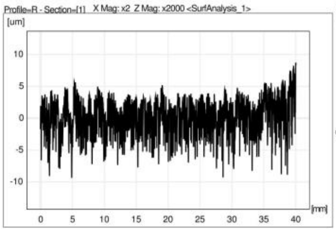
Profile=R - Section=[1]		Lc	8.0mm	Smooth Connection	Off
Standard	OLDMIX	Kind of Filter:	Gaussian	Mean Line Compensation	On
Kind of Profile:	R	Evltn Length(lm):	40.0mm	Compensation:	R-Curve(Auto) All
Smplg Length(le):	8.0mm	Pre-Travel:	4.0mm		
No of Smplg(nle):	5	Post-Travel:	4.0mm		

Surface Texture Measurement Result

Calculation Result

Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value	Meas Cont	Meas Value
Roughness 2D<SurfAnalysis_1>		Ry	14.4007um	Rt3	12.3938um	Rt	17.6012um		
Profile=R - Section=[1]		Rt1	15.0077um	Rt4	14.1016um	Rz	12.7035um		
Ra	2.1905um	Rt2	12.9109um	Rt5	17.5896um	da	6.1075degree		

Profile=R - Section=[1] X Mag: x2 Z Mag: x2000 <SurfAnalysis_1>



Parameter Summary Sheet

Parameter	Profile=R - Section=[1]	Average Value
Ra (um)	2.1905	2.1905
Ry (um)	14.4007	14.4007
Rt1 (um)	15.0077	15.0077
Rt2 (um)	12.9109	12.9109
Rt3 (um)	12.3938	12.3938
Rt4 (um)	14.1016	14.1016
Rt5 (um)	17.5896	17.5896
Rt (um)	17.6012	17.6012
Rz (um)	12.7035	12.7035
da (degree)	6.1075	6.1075