Magnetic Coil:

Assembly and Instruction Manual

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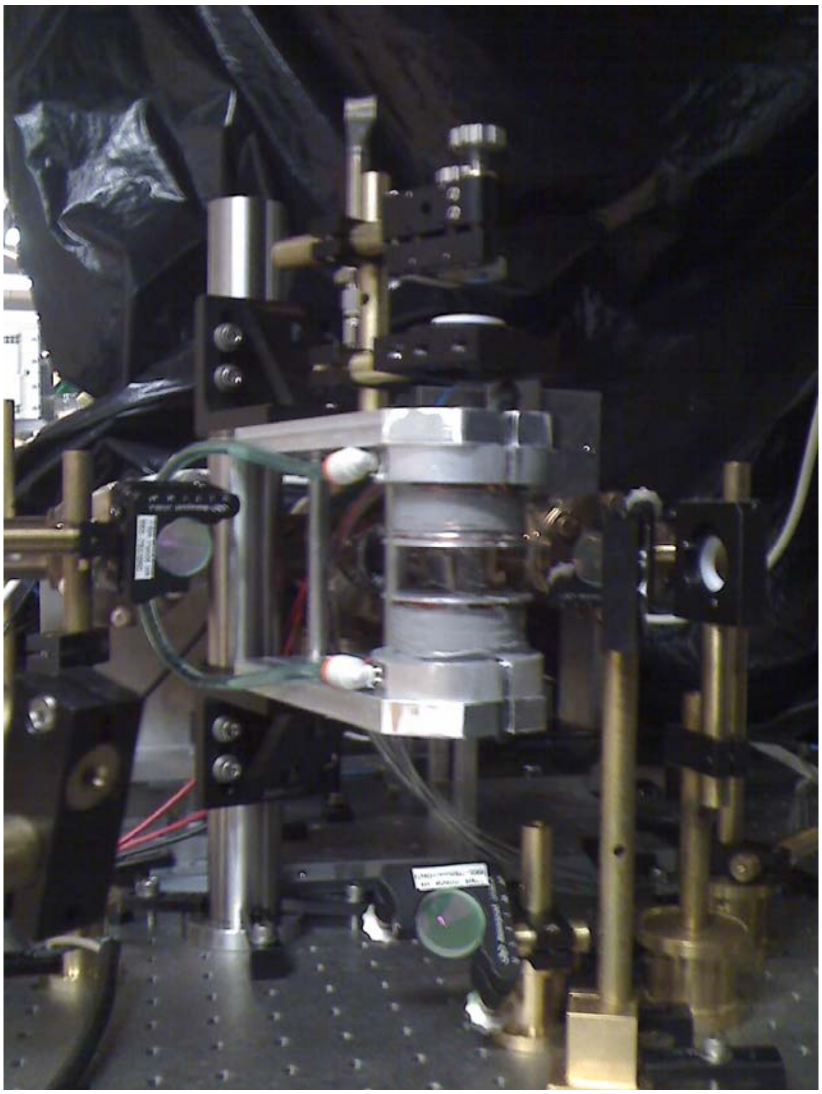

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Appendix

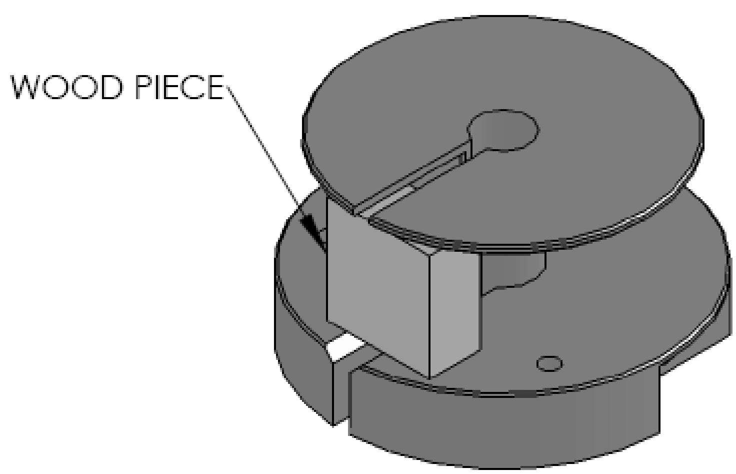
BOM QDG-0001A	COIL REEL ASSEMBLY
BOM QDG-0002A	MAGNETIC COIL ASSEMBLY
PRODSPEC QDG-0002A	MAGNETIC COIL ASSEMBLY
DWG QDG-0001A	COIL REEL ASSEMBLY
DWG QDG-0002A	MAGNETIC COIL ASSEMBLY
DWG MMC-0001A	COIL REEL - MECHANICAL
DWG MMC-0002A	COIL BASE - MECHANICAL
DWG MMC-0003A	ALIGNER ROUND – MECHANICAL
DWG QDG-XXXXX	FEEDTHROUGH - CONCEPT

1.0 Introduction

The following will provide necessary details to machine and assemble a magnetic coil. Drawings of the custom components will be provided along with a Bill of Materials (BOM) to list all necessary components for the assembly. Lastly measured data of a test coil will be provided along with necessary analysis to achieve necessary magnetic field gradients while keeping the temperature of the coils below the maximum operating point.

2.0 Machining Instructions (Coil Reel)

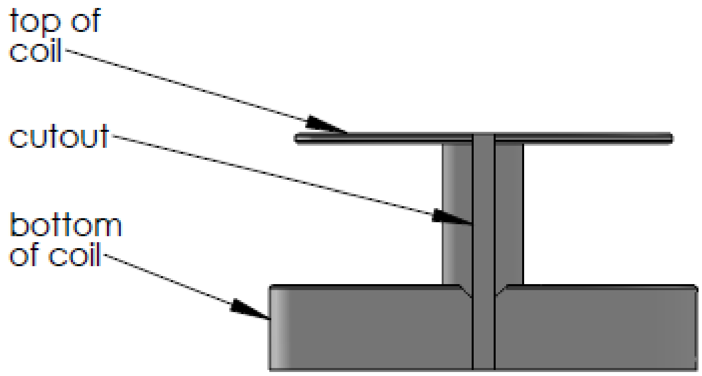
Care must be taken during the machining of the Coil Reels. Since the thickness of the top of the reel is only 1.5mm it is susceptible to warping. This mainly presents a problem when the 1/8 '' cutout is made to prevent eddy currents. Thus to achieve a minimally warped surface during the milling of the slots, a support piece (wood was used) should be placed as shown in the figure below (colors not exact).



Next care should be taken to smooth out all surfaces that will come into contact with the Kapton coated copper wire. This is achieved simply using sandpaper. Also, the chamfer on the bottom plate can be created using a file followed by using sandpaper for a smooth finish.

3.0 Assembly Instructions (Coil Reel)

The following terms will be used in the rest of the assembly instructions as provided in the picture below.



The assembly instructions are provided in the steps below. Note that prior to starting the procedure, the leading end of the Kapton coated Copper wire should be terminated with a banana plug to allow for testing for short circuiting during the assembly procedure. If the reel is not wound carefully there is chance of the Aluminum reel scratching the Kapton off the wire and shorting to the base. Thus once a layer of wire has been wound, the assembler should plug in the terminated end into a Digital Multi-Meter (DMM) and probe the base to ensure that the resistance is maximum (open circuit is displayed as 0 M on the DMM). Ensure to keep the copper wire under tension during the coiling process.

3.1 Initial Set up

3.1.1 Terminate end of Copper wire with banana plug.

3.1.2 Place coil reel onto lathe chuck such that the chuck is pressing the thick base. Ensure that base is exposed approximately 5mm past chuck, and is spinning concentrically.

3.1.3 Place banana plug terminated end through reel hole and through the lathe hole such that it sticks out about 50cm.

3.1.4 Place thermal epoxy on 12mm diameter round space of reel.

3.1.5 Spin lathe in clockwise direction (looking down on reel from the top) manually and ensure even coil spacing. If required use **plastic** card to ensure there is NO spacing between coils.

3.1.6 When approached end, place thermal epoxy on the wound coils and repeat previous step to wind coils back toward the base.

3.2 Coiling

3.2.1 After coiling reaches end, cut strip of 21mm wide Aluminum foil such that wrapping the foil around the coils will leave a 5-10mm gap at the cutout of the coil reel. This will avoid eddy currents.

3.2.2 Apply epoxy to both sides of the foil and place it over the coils. Ensure that it is tight and not overlapping the cutout of the coil reel.

3.2.3 Proceed coiling another layer of wire.

3.2.4 Apply thermal epoxy on the exposed coils and proceed coiling another layer of wire towards the chuck.

3.2.5 Continue coiling as provided by procedure 3.2 until the number of coils specification is reached.

3.3 Coil Termination

3.3.1 After completing the coiling process, cut wire 50 cm past final coil winding.

3.3.2 Place thermal epoxy over the final exposed coil reel (this step is optional depending of aesthetic requirements).

3.3.3 Pass the cut wire through the slit at the bottom of the base.

3.4 Coil Wiring

3.4.1 The banana jack color coiling is as follows. The final assembly should have the top coil red connector be connected to current supply. The top coil black connector be connected to bottom coil red connector. Lastly the bottom coil black connector should be connected to the current supply.

3.4.2 To achieve this use standard soldering procedures ensuring that the copper wires from the base are approximately 20 cm long and wound together. The banana jacks should be 50 cm long. Also, place heat shrink around the individual solder joints as well as over the wound copper pair.

3.5 Attachments

3.5.1 Place Teflon Tape on Quick Connect NPT end and screw it into base of coil reel using wrench. Repeat this procedure for both connects.

4.0 Assembly Instructions (Magnetic Coil)

4.1 Using the documents BOM-QDG-0002A and DWG-DQG-0002A, the magnetic coil assembly will be trivial.

4.2 To ensure that both coils are along the same axis, the alignment jig can be used to slide through both holes. If the alignment is good, the jig will slide through both easily. If this is not the case, loosen the screws on either the coils or alignment rounds until it does, then tighten screws again.

4.3 Ensure to test the water flow up to maximum flow pressure prior to setting up coil in experiment.

4.4 Check the assembly for short circuits prior to connecting coils to power supply.

5.0 Final Steps

5.1 Align coils to fit in the MOT setup.

5.2 Perform alignment for MOT, it is possible to use the 1/4-20 rail on the coil reel base to support the Z-axis optics.

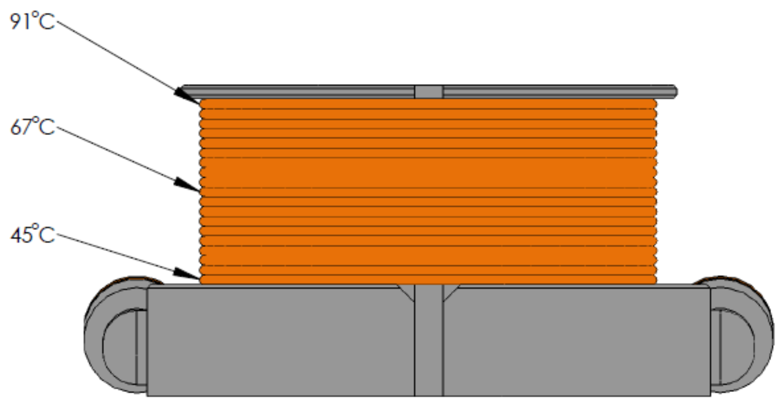
6.0 Thermal Data

Thermal response need to be taken into account in order to estimate the cooling time for the coils for currents greater than 12A. The coils will work continuously for currents lower than 12A, however they will smoke for larger currents. The maximum operating temperature of the coils is 150^{0}C. Hence cooling cycles need to be implemented for larger currents.

Temperature was measured using a standard K-type thermocouple pressed to the topmost winding. Water cooling was applied during all experiments. The measurement comprised of using a current source (30A max) connected to the coils. A voltage meter was applied in parallel to the coils and readings were taken.

6.1 Temperature Distribution

Winding temperature for a 10A current in steady state is shown below.



It is clear that the top of the coils is the hottest since it is furthest away from the cooling block. Due to this, all following temperature measurements are made on the topmost winding and hence the maximum temperature of the coil.

6.2 Heating Transient Data

During the following experiment, various currents were applied and voltage and temperature were recorded.

Time (sec)	Current (A)	Voltage (V)	Power (W)	Resistance (Ω)	Temp (C)
0	6.09	4.018	24.47	0.660	11.39
30	6.09	4.085	24.88	0.671	16.89
60	6.09	4.14	25.21	0.680	21.40
120	6.09	4.22	25.70	0.693	27.97
180	6.09	4.27	26.00	0.701	32.07
240	6.09	4.3	26.19	0.706	34.54

Table 1: Measurements for 6.09 A current

Time (sec)	Current (A)	Voltage (V)	Power (W)	Resistance (Ω)	Temp (C)
0	10.12	7.23	73.17	0.714	32.07
15	10.12	7.34	74.28	0.725	36.20
30	10.12	7.48	75.70	0.739	41.47
45	10.12	7.59	76.81	0.750	45.60
75	10.12	7.8	78.94	0.771	53.49
100	10.12	7.87	79.64	0.778	56.12
120	10.12	7.97	80.66	0.788	59.88
135	10.12	8.03	81.26	0.793	62.14
180	10.12	8.23	83.29	0.813	69.66
Equilib.	10.12	8.86	89.66	0.875	93.34

Table 2: Measurements for 10.12 A current

Time (sec)	Current (A)	Voltage (V)	Power (W)	Resistance (Ω)	Temp (C)
0	12.4	7.99	99.08	0.644	13.00
30	12.4	8.60	106.64	0.694	22.00
60	12.4	9.17	113.71	0.740	38.00
90	12.4	9.60	119.04	0.774	52.00
120	12.4	10.10	131.44	0.815	66.80
150	12.4	10.33	128.09	0.833	76.80
180	12.4	10.64	131.94	0.858	86.70
240	12.4	11.12	137.89	0.897	101.60
300	12.4	11.48	142.35	0.926	112.70
360	12.4	11.75	145.70	0.948	121.40
420	12.4	11.97	148.43	0.965	127.80
480	12.4	12.13	150.41	0.978	132.60
540	12.4	12.24	151.78	0.987	136.10
600	12.4	12.33	152.89	0.994	138.70
660	12.4	12.40	153.76	1.000	141.20
720	12.4	12.45	154.38	1.004	142.70
780	12.4	12.49	154.88	1.007	143.50
840	12.4	12.51	155.12	1.009	144.10
900	12.4	12.54	155.50	1.011	144.80
960	12.4	12.55	155.62	1.012	145.30
1020	12.4	12.57	155.87	1.014	145.70
1080	12.4	12.57	155.87	1.014	146.20
1140	12.4	12.57	155.87	1.014	146.20

Table 3: Measurements for 12.4 A current

Note: The temperature was physically measured only for the 12.4 A current. The temperatures for the other two currents were based on the resistance. A temperature versus resistance function was found for the 12.4 A current and based on this, the temperatures for the other currents were estimated.

6.3 Cooling Transient

Cooling transient data was obtained by heating the coils to 150^{0}C, disconnecting the power supply and measuring the temperature. The data is presented below.

Time (sec)	Temp (C)
0	153.50
10	151.20
20	144.20
30	137.90
40	130.80
50	123.70
60	115.40
70	108.30
80	101.50
90	95.80
100	90.10
110	84.00
120	79.30
130	75.00
140	70.00
150	66.10
160	62.20
170	58.00
180	55.10
210	45.80
240	39.00
270	33.30
300	29.00
330	25.60
360	22.70
420	18.80
480	15.90
540	14.10
600	13.20
660	12.50
720	12.10
780	10.90
840	11.50

Table 4: Cooling Temperature Data

6.4 Thermal Analysis

Thermal rise rates and cooling cycle times are addressed here.

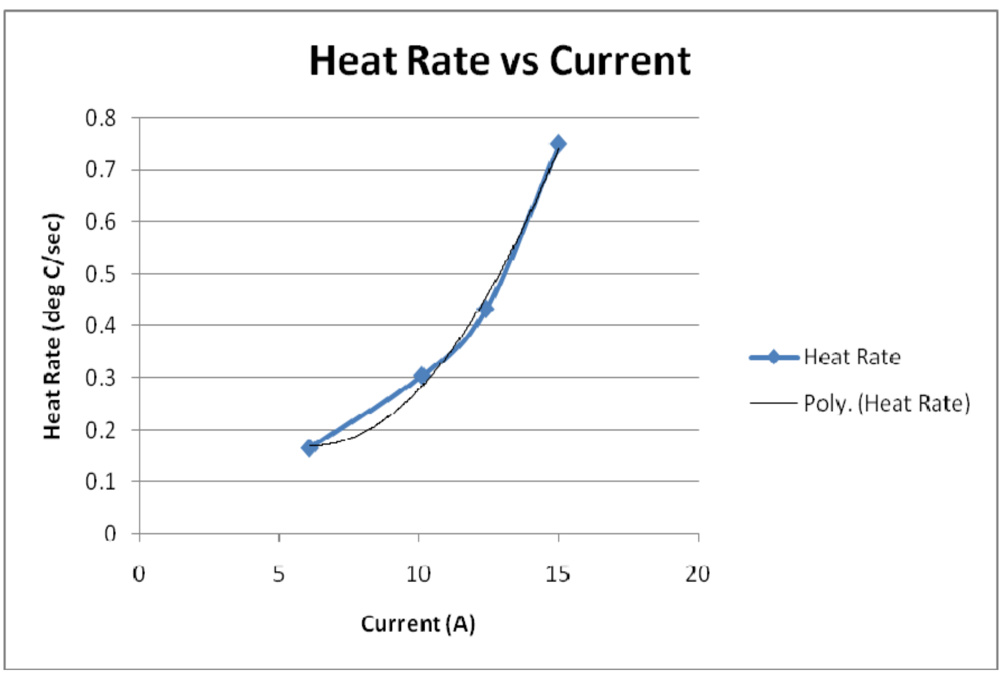
6.4.1 Thermal Rise Rate

By taking the natural log of the temperature gradients versus time, the heating constant can be found by a linear fit of this curve. The heating constants are given as follows:

Current (A)	Heat Rate (1/sec)
6.09	0.00777
10.12	0.00617
12.40	0.00463

It is somewhat ambiguous whether as to what function to fit these points. Although fitting the inverse to a quadratic looks promising. However a different approach shall be taken. By observation, currents greater than 12A have a linear temperature rise in the temperature range of 0-150^{0}C, thus only the linear portions of the heating curves are fit below to produce the following rates. Additional data from 15A heating cycle is also used.

Current (A)	Heat Rate (deg C/sec)
6.09	0.166
10.12	0.305
12.40	0.433
15.00	0.750



Fitting was done using a quadratic function since power dissipation is proportional to the square of the current. The heat rate, k, is given by the function:

$$k(I) = 0.007\, I^2 - 0.089\, I + 0.442$$

This will be used for the cycling analysis.

6.4.2 Cooling Cycle Analysis

Cycle analysis criteria will require the following:
Temperature Maximum: 110^0C
Current ON time: 30 sec

Based on these specifications, the cooling time will be established.
The temperature of the coils during cooling is given by the following function:

$$T(t) = 142*\exp(-0.0072\, t) + 11.5$$

By multiplying the heat rate by 30 seconds, the cooling temperature difference is provided. Utilizing this value, the cooling time can be found from the equation above. Cooling times are provided for currents ranging from 13A to 30A below.

Current (A)	Heat Rate (deg C/sec)	Temp Rise after 30 sec (deg C)	Cooling Time (sec)	Max Voltage Drop for 2 coils (V)	Max Coil Temp. (C)
13	0.468	14.0	22	24.05	110.0
14	0.568	17.0	27	25.90	110.0
15	0.682	20.5	33	27.75	110.0
16	0.810	24.3	40	29.60	110.0
17	0.952	28.6	48	31.45	110.0
18	1.108	33.2	58	33.30	110.0
19	1.278	38.3	69	35.15	110.0
20	1.462	43.9	83	37.00	110.0
21	1.660	49.8	99	38.85	110.0
22	1.872	56.2	118	40.70	110.0
23	2.098	62.9	142	42.55	110.0
24	2.338	70.1	174	44.40	110.0
25	2.592	77.8	217	46.25	110.0
26	2.860	85.8	285	48.10	110.0
27	3.142	94.3	438	49.95	110.0
28	3.438	103.1	620	51.80	114.6
29	3.748	112.4	650	54.98	123.9
30	4.072	122.2	680	59.22	133.7

Table 6: Cooling Specifications

7.0 Future Recommendations

7.1 Current Assembly

It is recommended that the current coils have an online temperature measurement system that is incorporated into the software. This would be comprised of a thermocouple attached to a top winding, connected to a readout device that can communicate with the computer. Thus if it occurs that the temperature exceeds a set value, the current controller would be disabled.

7.2 Future High Field Magnetic Coils

Higher gradient requirements will require more efficient cooling. Future designs should encase the coils in a water cooled case as in previous designs. Furthermore, the coils should be wound on a jig prior to putting inside the case in order to avoid winding problems and enable efficient assembly. Also, rather than soldering the wire leads out of a copper tube, a feed through should be designed using a Swagelok and custom made Teflon or rubber ferrule. A concept drawing of this is presented in the appendix.

8.0 Conclusion

The magnetic coils were assembled and adopted into the MOT experiment. They were able to produce an atom cloud and should contribute to further experiments. The coils should exceed the 200G/cm gradient specification initially provided. The final alignment included placing the Z-axis optics on the 1/4-20 slots on the top Coil Reel Base to free up space on the optical table.

Bill Of Material

Parent Part Number:	QDG-0001A	Revision:	A			Parent Part Description:	COIL-REEL-ASSEMBLY

ITEM	Part Name	UOM	Qty.	Manuf	Manuf Part #	Unit Price (US)	Extension
1	COIL REEL	EA	1.0	UBC/PD			0.00
2	18-GUAGE COPPER WIRE - KAPTON COATED	M	4	UBC			0.00
3	ALUMINUM STRIP - 21 MM WIDTH	EA	9	UBC			0.00
4	PASTE-THERMAL EPOXY	ML	10	COTRONICS	132 IP	0.17	1.69
5	QUICK FIT 1/4" TUBE - 1/16 NPT SWIVEL ELBOW	EA	2	MCMASTER	52065K128	4.13	8.26
6	HEAT SHRINK - 4MM ID	CM	40	UBC			0.00
7	CONNECTOR - BANANA - RED	M	0.5	UBC			0.00
8	CONNECTOR - BANANA - BLACK	M	0.5	UBC			0.00
REA:	PD				Date:	2-May-2009	Total 9.95

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Bill Of Material

Parent Part Number:	QDG-0002A	Revision:	A			Parent Part Description:	MAG COIL-ASSEMBLY

ITEM	Part Name	UOM	Qty.	Manuf	Manuf Part #	Unit Price (US)	Extension
1	COIL REEL ASSEMBLY	EA	2.0	UBC/PD	QDG-0001A	9.95	19.90
2	MOUNTING POST BASE - 2.4 DIA - 0.40 HEIGHT	EA	1.0	THORLABS	PB1	23.70	23.70
3	MOUNTING POST BRACKET (IMPERIAL 1/4-20)	EA	2.0	THORLABS	C1505	90.00	180.00
4	MOUNTING POST - 1.5" DIA-350mm LONG	EA	1.0	THORLABS	P14	76.20	76.20
5	COIL BASE	EA	2.0	UBC/PD			0.00
6	ALIGNER ROUND	EA	2	UBC/PD			0.00
7	SHSC - 6-32 - 0.5" LONG	EA	6	UBC			0.00
8	SHSC - 8-32 - 0.5" LONG	EA	4	UBC			0.00
9	SHSC - 1/4-20 - 0.5" LONG	EA	5	UBC			0.00
10	WATER TUBING- 1/4" OD	M	10	UBC			0.00
REA:	PD				Date:	2-May-2009	Total 299.80

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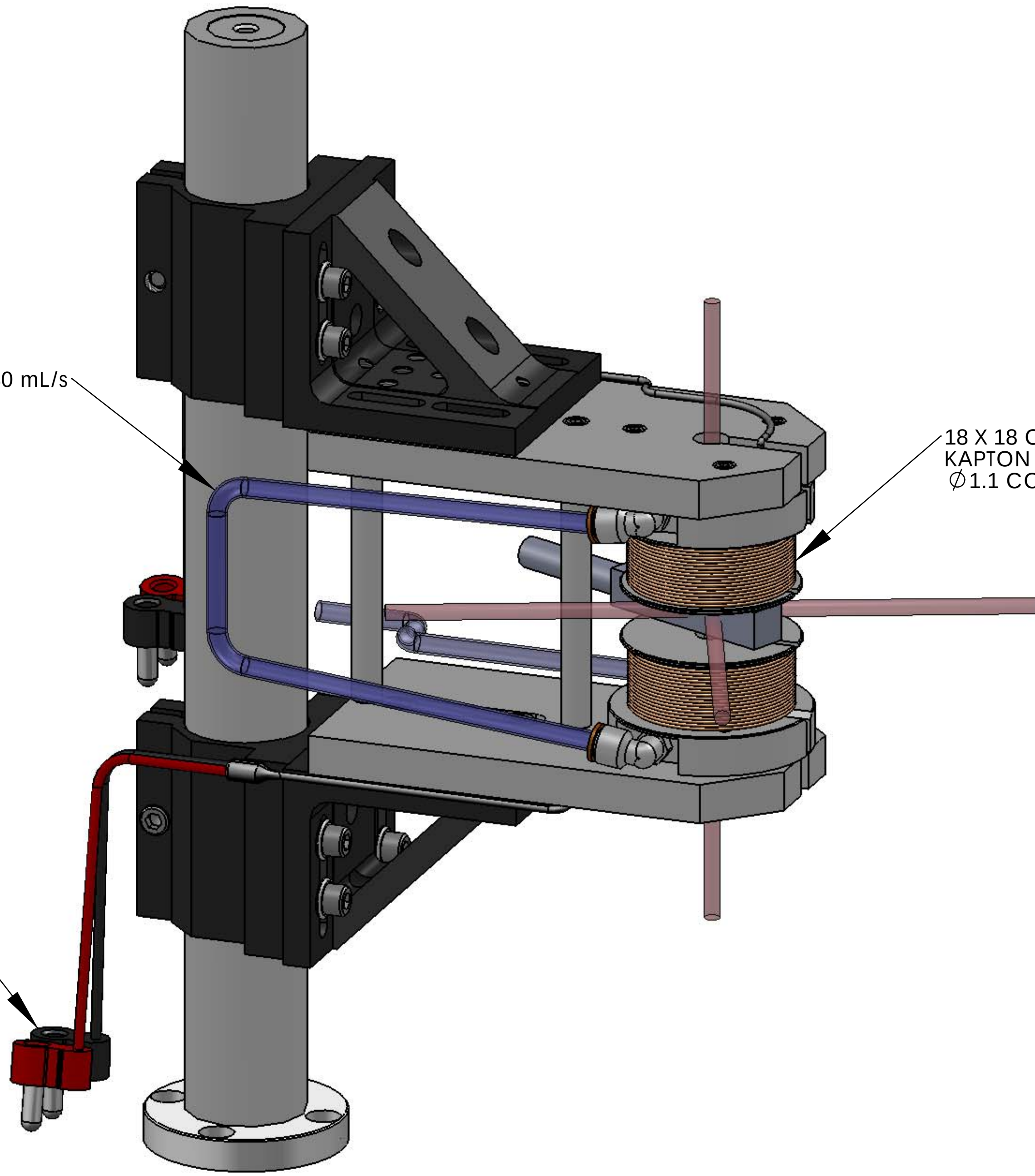
REV.	DESCRIPTION		DATE	DES. BY	REV.	DESCRIPTION	ECO No.	DATE	DES. BY
1	PRODUCT SPECIFICATION		04-MAY-09	P.DJURICANIN					



NOTES: UNLESS OTHERWISE SPECIFIED

1. DIMENSIONS IN MILLIMETERS [INCHES]
2. OPERATING TEMPERATURE: 0-150 C
3. MAGNETIC GRADIENT: 40 G/cm A
4. SS CURRENT OF 12A PROVIDES TEMPERATURE OF 140 C

TOLERANCES:

LINEAR: (MM)		ANG (DEG)		MACH SURFS
X	±0.3	X.	±0.5°	1.6
X.X	±0.15	X.X	±0.1°	
X.XX	±0.05	X.XX	±0.05°	
X.XXX	±0.025			

TITLE: PROD SPEC
MAG COIL ASSEMBLY

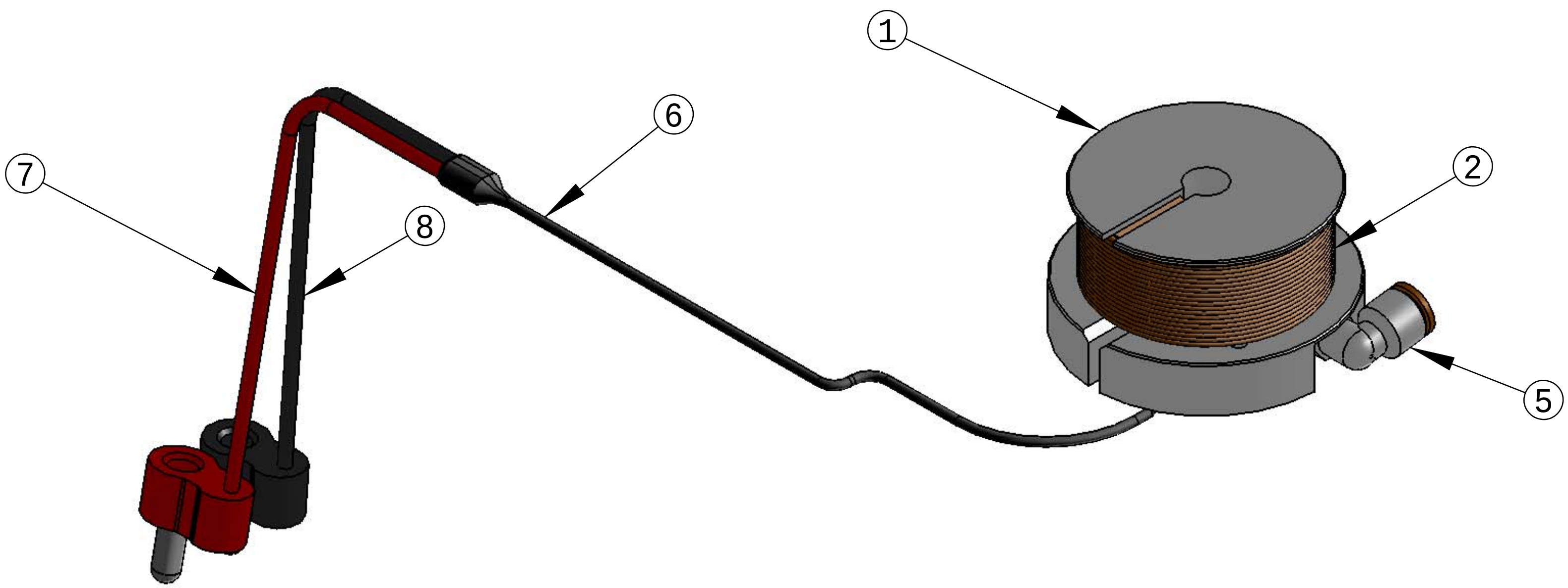
PART NO. QDG-0002A

REV 1

SHEET 1 OF 1

TMPLT-ENG-DWG-ASIZE-C

REV.	DESCRIPTION		DATE	DES. BY	REV.	DESCRIPTION	ECO No.	DATE	DES. BY
A	ENG. DRAWING		04-MAY-09	P.DJURICANIN					



NOTES: UNLESS OTHERWISE SPECIFIED

1. NUMBERS AS PER BOM-QDG-0001A
2. ALUMINUM STRIPS (3) AND THERMAL EPOXY (4) NOT SHOWN

TOLERANCES:			TITLE:	PART NO.	REV
LINEAR: (MM) X ±0.3 X.X ±0.15 X.XX ±0.05 X.XXX ±0.025	ANG (DEG) X. ±0.5° X.X ±0.1° X.XX ±0.05°	MACH SURFS 1.6	ASSEMBLY COIL REEL	QDG-0001A	A
					SHEET 1 OF 1

TMPLT-ENG-DWG-ASIZE-C

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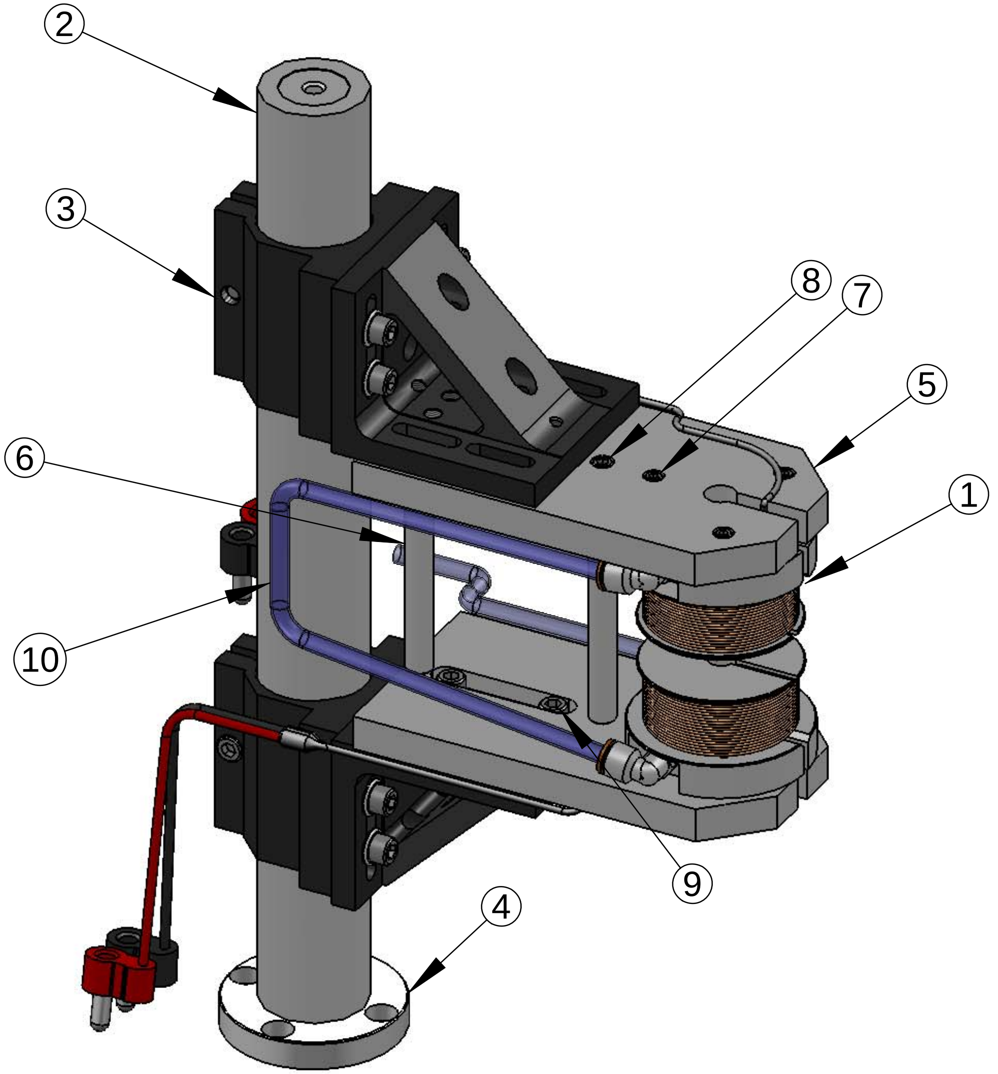
A	ENG. DRAWING		04-MAY-09	P.DJURICANIN					



NOTES: UNLESS OTHERWISE SPECIFIED

1. DIMENSIONS ARE IN MILLIMETERS [INCHES]
2. NUMBERS ARE AS PER BOM-QDG-0002A

TOLERANCES:

LINEAR: (MM)		ANG (DEG)		MACH SURFS
X	±0.3	X.	±0.5°	1.6
X.X	±0.15	X.X	±0.1°	
X.XX	±0.05	X.XX	±0.05°	
X.XXX	±0.025			

TITLE: ASSEMBLY MAG COIL

PART NO. QDG-0002A

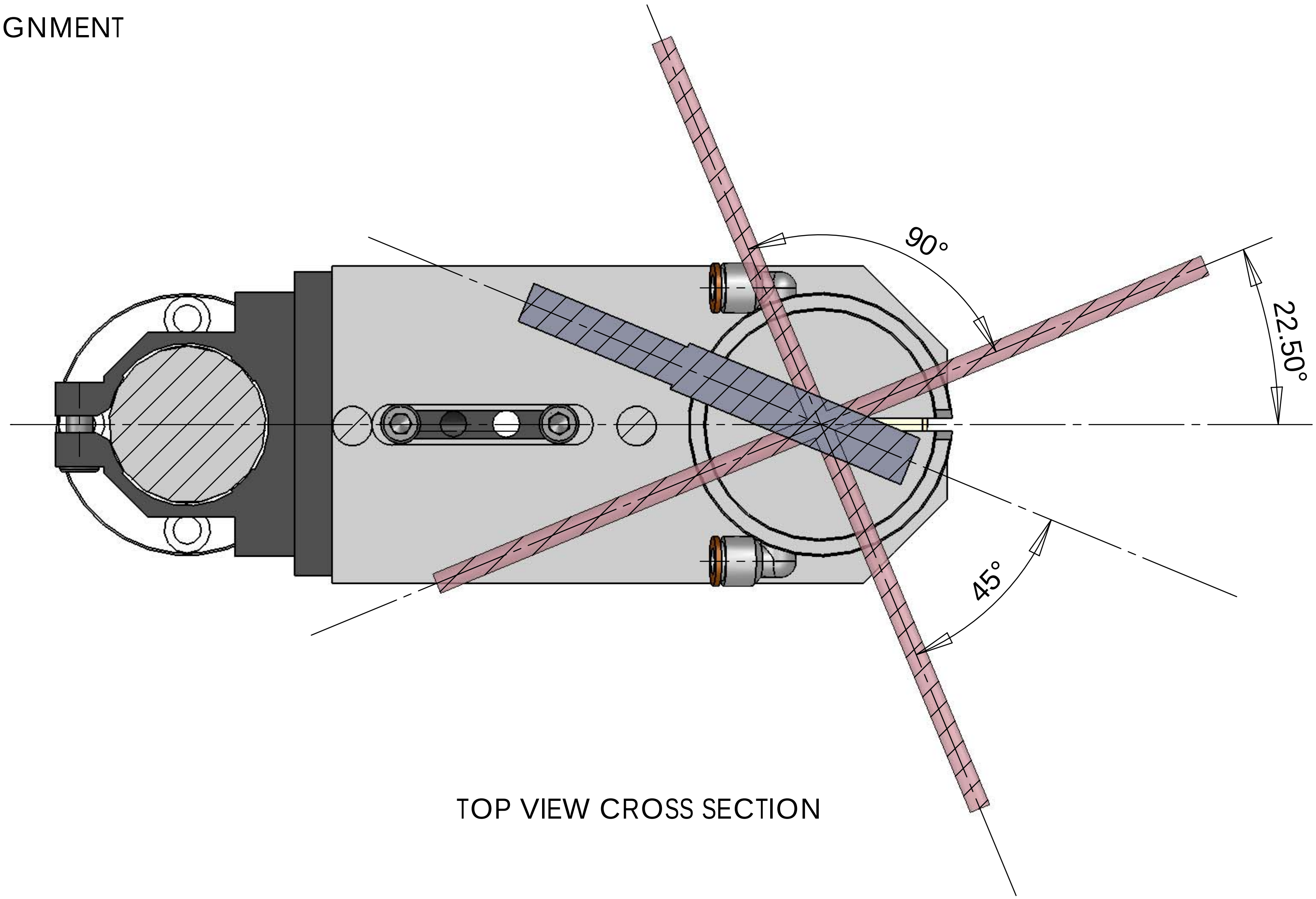
REV A

SHEET 1 OF 3

TMPLT-ENG-DWG-ASIZE-C

REV.	DESCRIPTION		DATE	DES. BY	REV.	DESCRIPTION	ECO No.	DATE	DES. BY
A	ENG. DRAWING		04-MAY-09	P.DJURICANIN					

OPTICAL ALIGNMENT



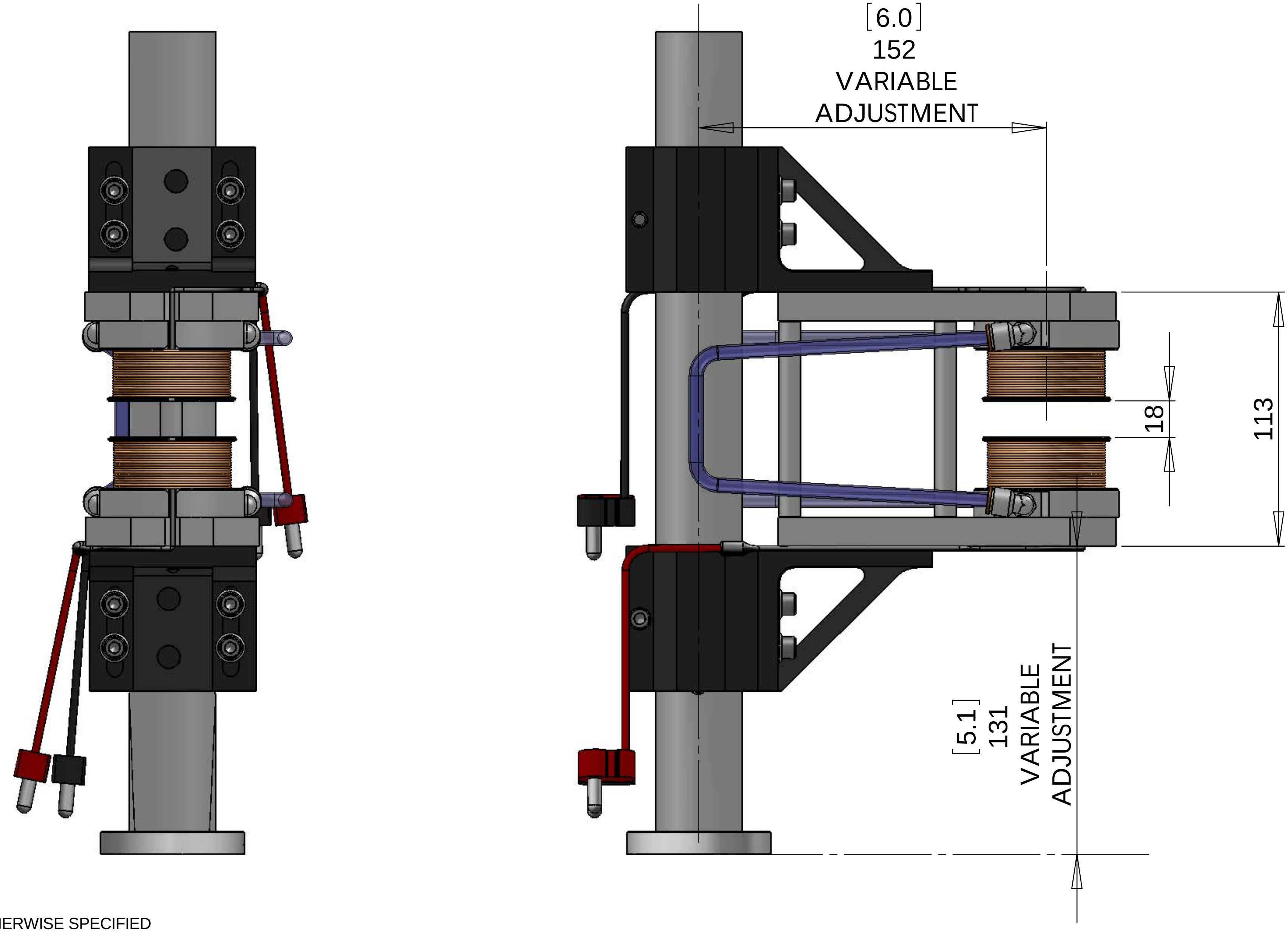
TOP VIEW CROSS SECTION

NOTES: UNLESS OTHERWISE SPECIFIED

1. DIMENSIONS ARE IN MILLIMETERS [INCHES]
2. NUMBERS ARE AS PER BOM-QDG-0002A

TOLERANCES:				TITLE:	PART NO.	REV
LINEAR: (MM)		ANG (DEG)	MACH SURFS	ASSEMBLY MAG COIL	QDG-0002A	A
X	±0.3	X. ±0.5°	1.6			SHEET
X.X	±0.15	X.X ±0.1°				2 OF 3
X.XX	±0.05	X.XX ±0.05°				
X.XXX	±0.025					

REV.	DESCRIPTION		DATE	DES. BY	REV.	DESCRIPTION	ECO No.	DATE	DES. BY
A	ENG. DRAWING		04-MAY-09	P.DJURICANIN					



NOTES: UNLESS OTHERWISE SPECIFIED

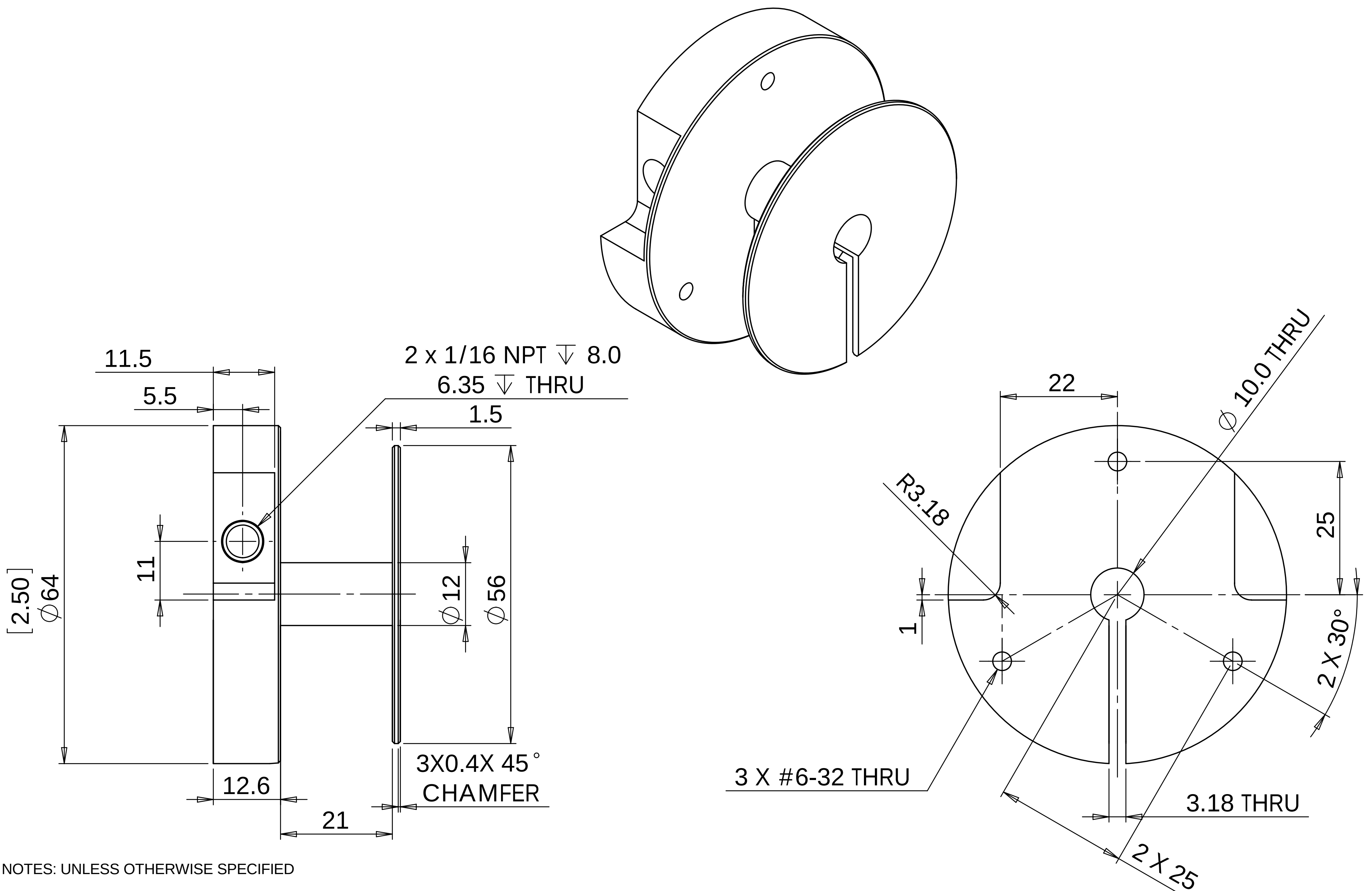
1. DIMENSIONS ARE IN MILLIMETERS [INCHES]
2. NUMBERS ARE AS PER BOM-QDG-0002A

TOLERANCES:					
LINEAR: (MM)		ANG (DEG)		MACH SURFS	
X	±0.3	X.	±0.5°	1.6	
X.X	±0.15	X.X	±0.1°		
X.XX	±0.05	X.XX	±0.05°		
X.XXX	±0.025				

TITLE: ASSEMBLY
MAG COIL

PART NO. QDG-0002A
REV A
SHEET 3 OF 3

REV.	DESCRIPTION		DATE	DES. BY	REV.	DESCRIPTION	ECO No.	DATE	DES. BY
A	ENG. DRAWING		18-MAR-09	P.DJURICANIN					



NOTES: UNLESS OTHERWISE SPECIFIED

1. DIMENSIONS ARE IN MILLIMETERS
2. MATERIAL: 6061 ALUMINUM
3. DEBURR & BREAK ALL EDGES
4. SURFACE FINISH: ANODIZE BLACK
5. DIMENSIONS APPLY AFTER ANODIZING

TOLERANCES:

LINEAR: (MM)		ANG (DEG)		MACH SURFS
X	±0.3	X.	±0.5°	1.6
X.X	±0.15	X.X	±0.1°	
X.XX	±0.05	X.XX	±0.05°	
X.XXX	±0.025			

TITLE: MECHANICAL COIL REEL

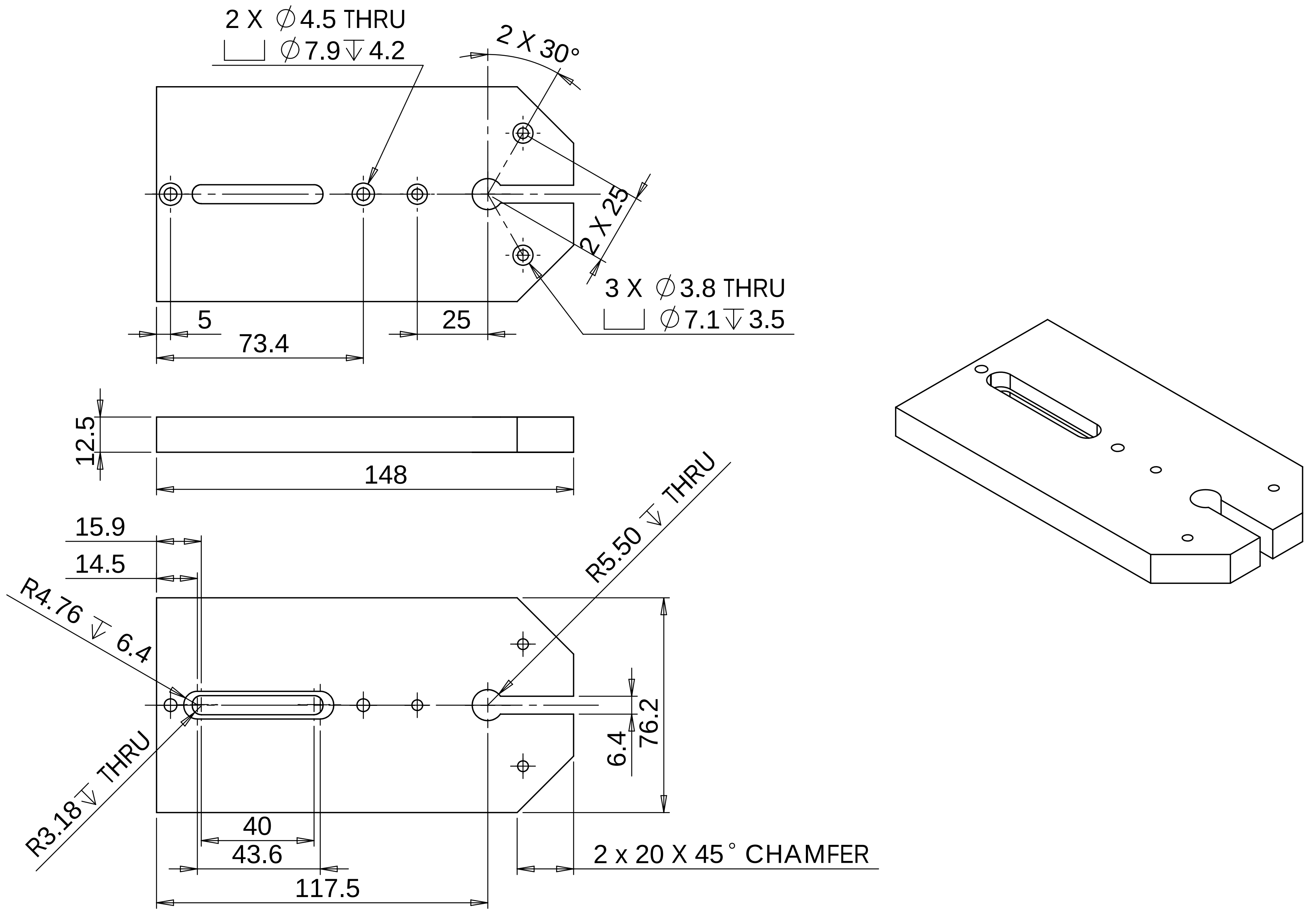
PART NO. MMC-0001A

REV A

SHEET 1 OF 1

TMPLT-ENG-DWG-ASIZE-C

REV.	DESCRIPTION		DATE	DES. BY	REV.	DESCRIPTION	ECO No.	DATE	DES. BY
A	ENG. DRAWING		16-MAR-09	P.DJURICANIN					



NOTES: UNLESS OTHERWISE SPECIFIED

1. DIMENSIONS ARE IN MILLIMETERS
2. MATERIAL: 6061 ALUMINUM
3. DEBURR & BREAK ALL EDGES
4. CLEAN USING ULTRASONIC CLEANER

TOLERANCES:

LINEAR: (MM)		ANG (DEG)		MACH SURFS
X	±0.3	X.	±0.5°	1.6
X.X	±0.15	X.X	±0.1°	
X.XX	±0.05	X.XX	±0.05°	
X.XXX	±0.025			

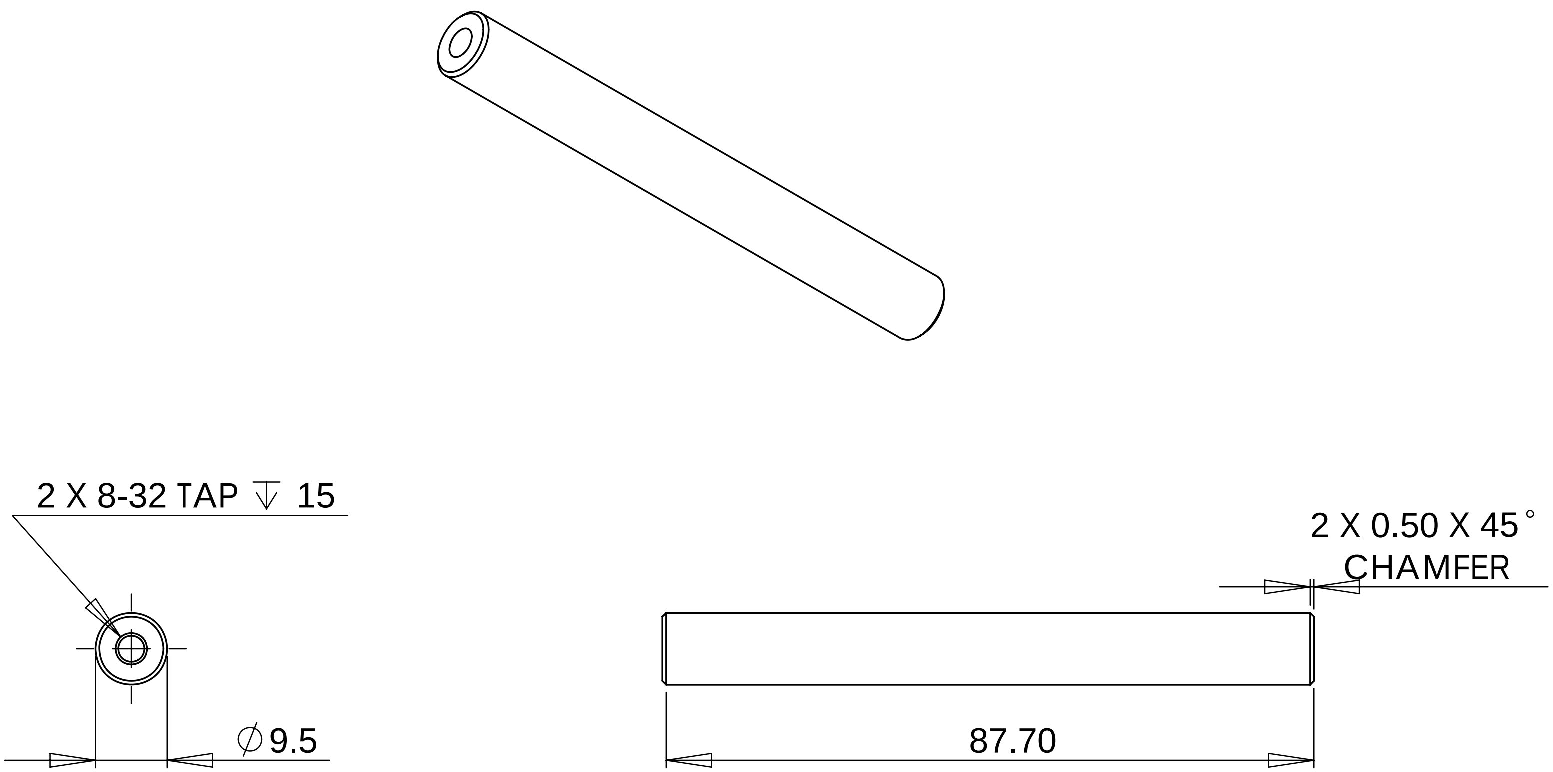
TITLE: MECHANICAL COIL REEL BASE

PART NO. MMC-0002A

REV A

SHEET 1 OF 1

REV.	DESCRIPTION		DATE	DES. BY	REV.	DESCRIPTION	ECO No.	DATE	DES. BY
A	ENG. DRAWING		16-MAR-09	P.DJURICANIN					



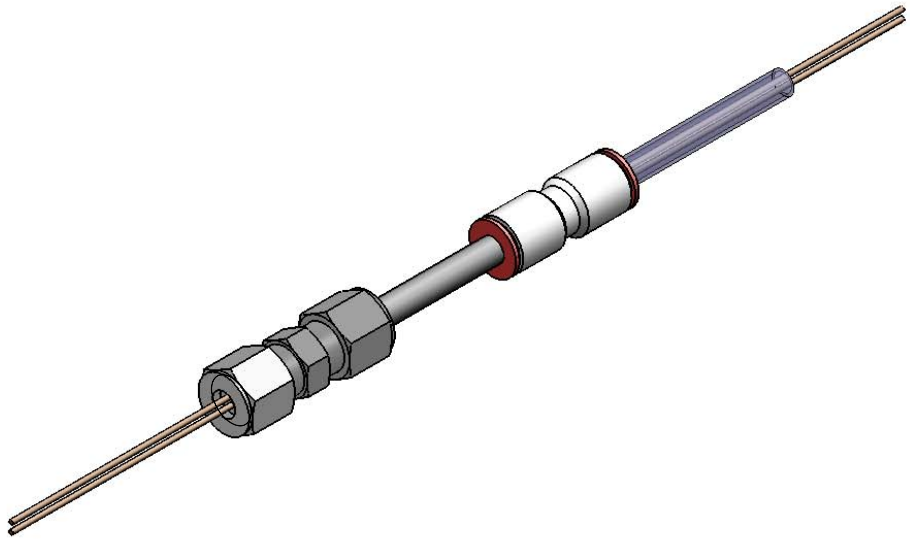
NOTES: UNLESS OTHERWISE SPECIFIED

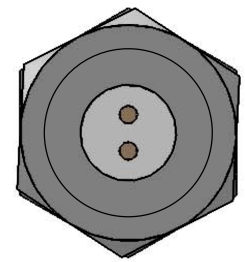
1. DIMENSIONS ARE IN MILLIMETERS
2. MATERIAL: 300 SERIES SS OR STEEL
3. DEBURR & BREAK ALL EDGES
4. CLEAN WITH ULTRASONIC CLEANER

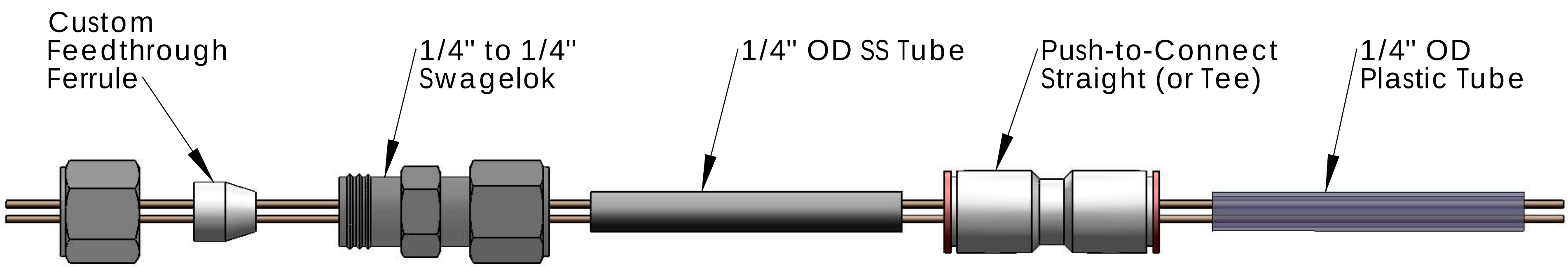
TOLERANCES:				TITLE:	PART NO.	REV
LINEAR: (MM) X ±0.3 X.X ±0.15 X.XX ±0.05 X.XXX ±0.025	ANG (DEG) X. ±0.5° X.X ±0.1° X.XX ±0.05°	MACH SURFS 1.6		MECHANICAL ALIGNER ROUND	MMC-0003A	A
						SHEET 1 OF 1

TMPLT-ENG-DWG-ASIZE-C

REV.	DESCRIPTION		DATE	DES. BY	REV.	DESCRIPTION	ECO No.	DATE	DES. BY
1	ENG. CONCEPT		04-MAY-09	P.DJURICANIN					







NOTES: UNLESS OTHERWISE SPECIFIED

1. DIMENSIONS ARE IN MILLIMETERS

TOLERANCES:
LINEAR: (MM)
X ±0.3
X.X ±0.15
X.XX ±0.05
X.XXX ±0.025

ANG (DEG)
X. ±0.5°
X.X ±0.1°
X.XX ±0.05°

MACH SURFS 1.6

TITLE: ASSEMBLY
FEEDTHROUGH FOR
COOLED COILS

PART NO. QDG-XXXX

REV 1

SHEET 1 OF 1