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High Temperature Superconductor test for dual bore quadrupole magnet design [1]

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Abstract

This paper reports results of the test of HTS conductor manufactured by Intermagnetics General Corporation (IGC). The HTS version of the CESR dual bore quadrupole magnet has been analyzed using data obtained in this test.

1 HTS test

The main purpose of the experiments described below was to obtain HTS characteristics needed for magnet design. The prime goal was to measure the HTS performance degradation versus bending radius and to investigate the following idea to reduce this degradation. This idea was to measure the difference between the effects of positive and negative strain, i.e., between strains caused by compression and by tension, and, using this difference, to optimize the HTS bending procedure.

The tested HTS conductor, provided by IGC, was a tape of 0.2" width and 0.008" thickness consisting of a layer of BSCCO-2223 material sheltered by silver. Three different samples, see figure 1, were tested. The first sample, S1, had stainless steel (SS) tape 0.001" thickness epoxied on HTS tape on the outside bending radius. Because the SS tape is much stiffer than the HTS conductor, the neutral axis was shifted out of the HTS to the SS tape. As a result, the bend caused negative strain, i.e., compression of the HTS material. On the second sample, S2, the stainless steel tape was attached on the inside of the bending

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R[in]	I_0	n
flat	30.59	13.23
2.25	37.00	7.18
2.00	35.27	7.60
1.50	40.28	5.37
1.00	38.14	5.25
0.75	34.24	4.98
0.50	27.82	5.26

Table 1: Parameters I_0 and n for different bending radius for sample S3, plain HTS conductor

radius. In this case the HTS tape is put into tension, i.e., positive strain. The third sample, S3, was without SS tape. Here the neutral axis was located close to the conductor center, so that half of the material had positive strain, while the other half had negative strain. All samples had an approximately equal length of 9". Two voltage taps 1.5" apart were located in the middle of each of them. Measurements were done at 77^oK (LN2 temperature).

Figures 2, 3 and 4 show the voltage between voltage taps as function of current for flat samples and for different bending radii. All samples had identical characteristics, when they were flat, and showed very different degradation with bending. Comparing plots corresponding to the same bending radius, say $1''$, for S1, figure 2, and for S2, figure 3, one can see that a negative strain caused less degradation than a positive one. However, the sample S3, see figure 4, indicated the smallest degradation for a given bending radius. This is because this sample had the smallest absolute value of strain, i.e., the smallest structure deformation in comparison with S1 and S2.

The conclusion which may be derived from the above measurements is that negative strain, i.e., strain due to compression, causes less HTS performance degradation than positive strain caused by tension. However, in any case, to get maximum HTS performance the strain must be at the lowest possible level.

All the data shown on figures 2, 3 and 4 have been fitted with the formula:

$$U[mV] = d * (I[A]/I_0)^n \tag{1}$$

were I_0 and n are free parameters, and d is the distance between voltage taps in inches. Table 1 shows the I_0 and n parameters for sample S3 for different bending radii. These parameters will be used in the next section to calculate HTS magnet characteristics.

2 HTS version of dual bore quadrupole magnet

The magnet described below is a HTS version of the magnet proposed in [1] and developed in [2]. Figure 6 gives a schematic view and figure 7 shows the HTS coil configuration. There are 2 coils per pole, i.e., 16 coils per magnet. They are of two types with slightly different dimensions. Both types of coils are approximately 60cm in length and are made with 38 turns of HTS conductor with characteristics identical to the one provided to us by IGC. The minimum bending radius at the coils ends is $1''$. Other coils dimensions given in figure 7. Using these parameters and the other magnet dimensions given in figure 6, we found that to excite $1T/m$ field gradient we need 8Amps of current. This calibration will be used below.

The measurements presented in Table 1 were done at 77^oK. To propagate the results to another operating temperature, we have to introduce a scaling factor for current, k, which is the ratio between the current at 77^oK and the current at another operating temperature which gives the same voltage drop per inch. In terms of this scaling factor and the parameters presented in Table 1, we can write the expression for power dissipation per $1''$ of conductor as:

$$P[mWatt] = \frac{I[A]^{n+1}}{(kI_0)^n} \tag{2}$$

Knowing the coil geometry, i.e., the total length of flat and bent conductor, we can obtain a formula for the power dissipated in one magnet. It is:

$$P_{magnet}[mWatt] = 2N_{coils}N_{turns}(L_f\frac{I^{n_f+1}}{(kI_{0f})^{n_f}} + 2\pi R_b\frac{I^{n_b+1}}{(kI_{0b})^{n_b}}) \tag{3}$$

Using the following numbers:

$$N_{coils} = 16; N_{turns} = 38; L_f = 25.56''(54.92cm); R_b = 1''(2.54cm) \tag{4}$$

as well as the parameters I_0 and n corresponding flat and bent coils with radius $1''$ (see table 1), we plot in figure 5 this power as a function of current. Here we used the scaling factor, k, equal to 1, 3, 4 and 5. For operating temperatures in range between 20^oK and 30^oK, the expected value for k is 4. For this k, the power dissipated in one magnet at 50Amp will be $1.2Watt$ and drops rapidly as the current decreases; see figure 5.

The power dissipated in the HTS coils will be calculated for 80 magnets in the arcs, with gradients corresponding to one of the recently used CESR optics files: h9818a700.ge7-4sa at energy $5.3GeV$. Table 2 shows the calculation of the total power dissipated by all 80 magnets.

The resulting numbers at the bottom of this table, $(47, 10 and 3.5 Watt)$ are quite small and give us some optimism regarding the application of HTS materials for future CESR upgrades.

$Quad$	$G[T/m]$	$I[A]$	$P[W]$ $k=3$	$P[W]$ $k=4$	$P[W]$ $k=5$
308	3.032	25.993	0.10	0.02	0.01
309	4.480	38.406	1.09	0.25	0.08
310	3.878	33.245	0.45	0.10	0.03
311	4.136	35.463	0.67	0.16	0.05
312	3.447	29.557	0.22	0.05	0.02
313	3.411	29.247	0.21	0.05	0.02
...	...	...	...	...	...
Total Power			47.0	10.83	3.49

Table 2: Dissipated power

3 Conclusion

The HTS conductor manufactured by IGC has been tested. It was found that this conductor at $30^o K$ of operating temperature may be used to build dual bore quadrupole magnets proposed for the CESR upgrade project. The amount of power dissipated in the HTS conductor in all the magnets will be in the range of a few tens of Watts.

References

[1] D. Rubin and M. Tigner, CON 94-28, Shared Bends and Independent Quadrupoles

[2] A. Mikhailichenko and D. Rubin, CLNS 96/1420, Concentric Ring Colliding Beam Machine with Dual Aperture Quadrupoles

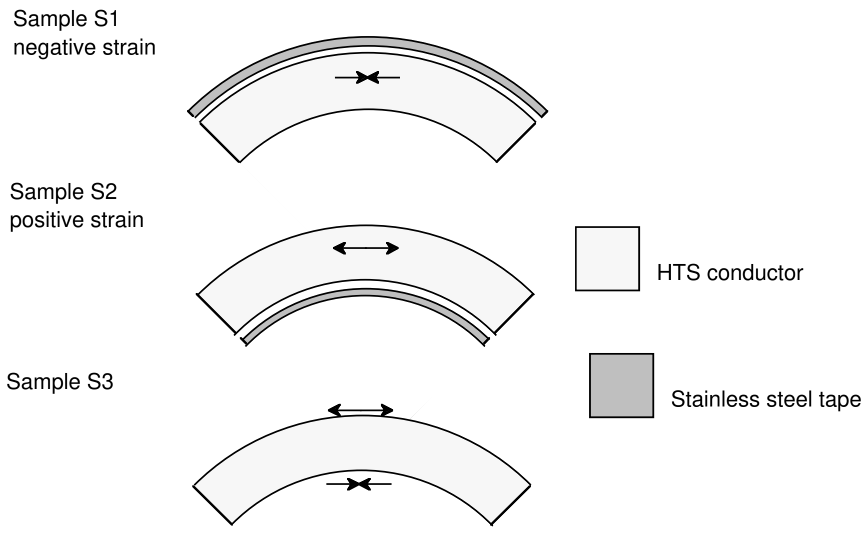

Figure 1: Schematic view of tested samples.

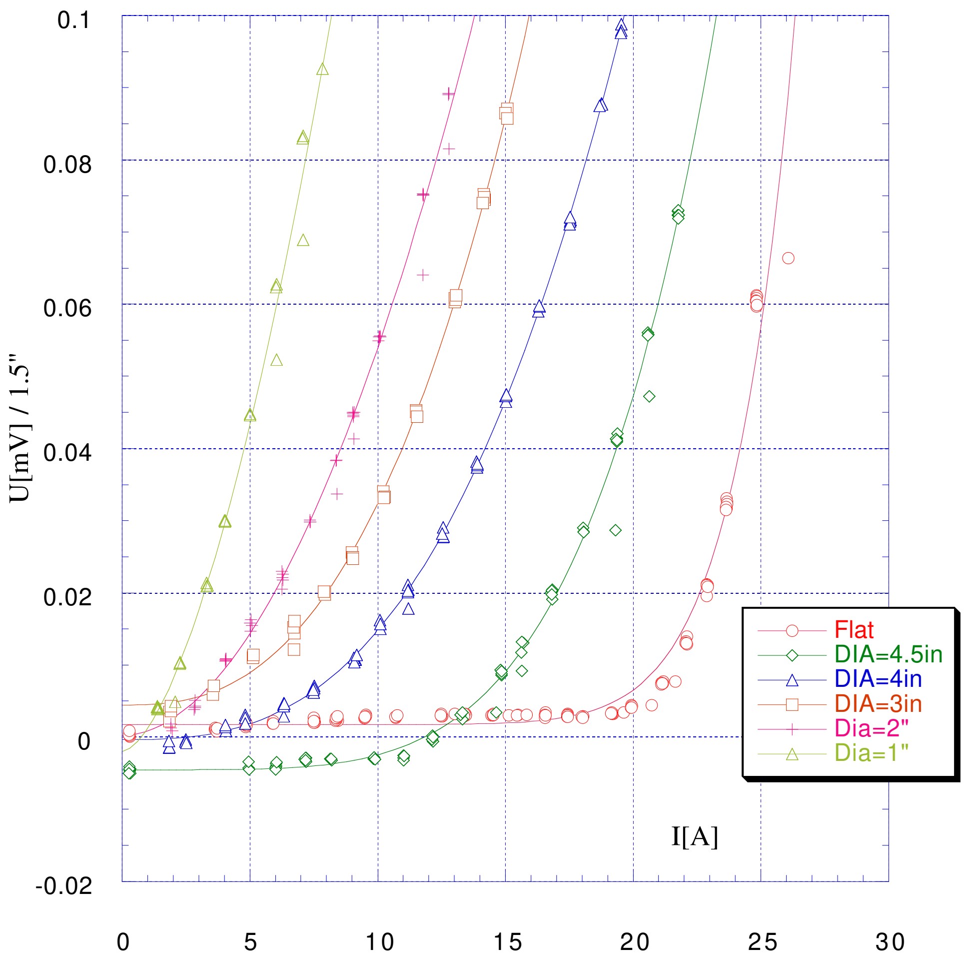

Figure 2: Sample S1, case of compression, i.e., negative strain. Voltage between two taps of 1.5” apart versus flowing current for different bending radius.

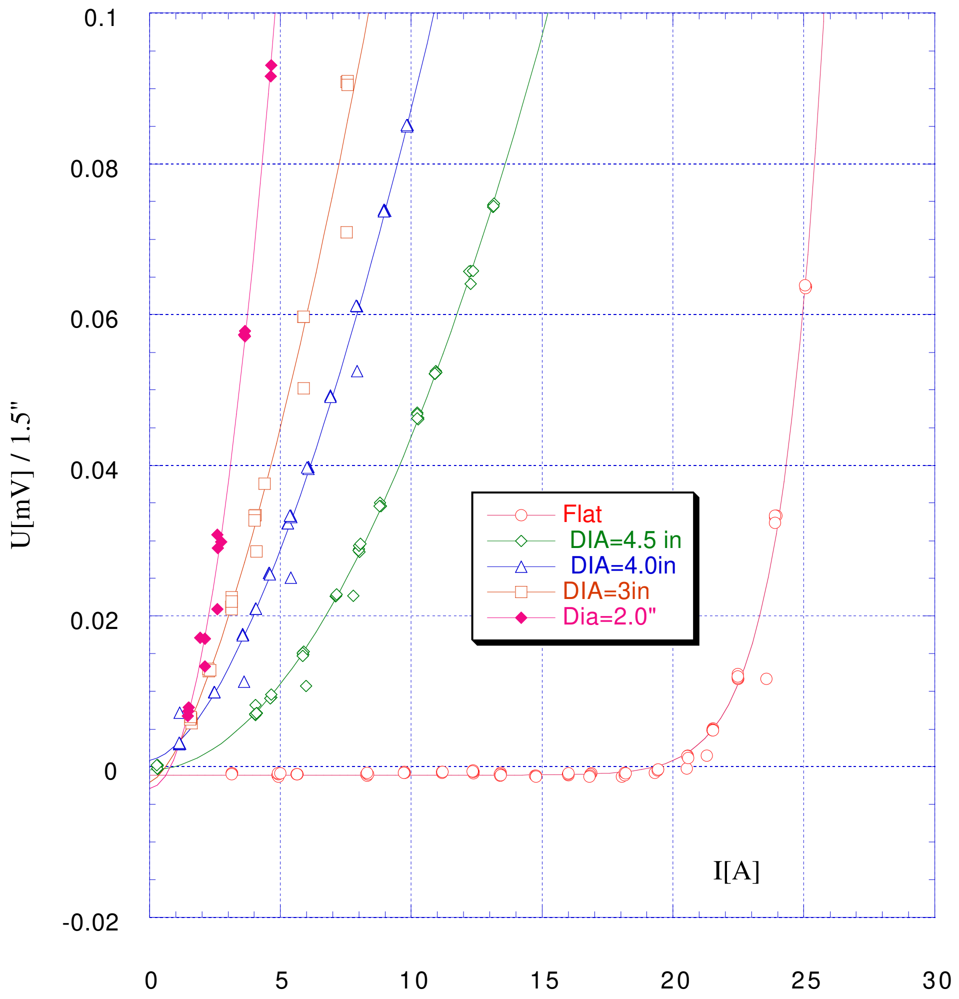

Figure 3: Sample S2, case of tension, i.e., positive strain. Voltage between two taps of 1.5” apart versus flowing current for different bending radius.

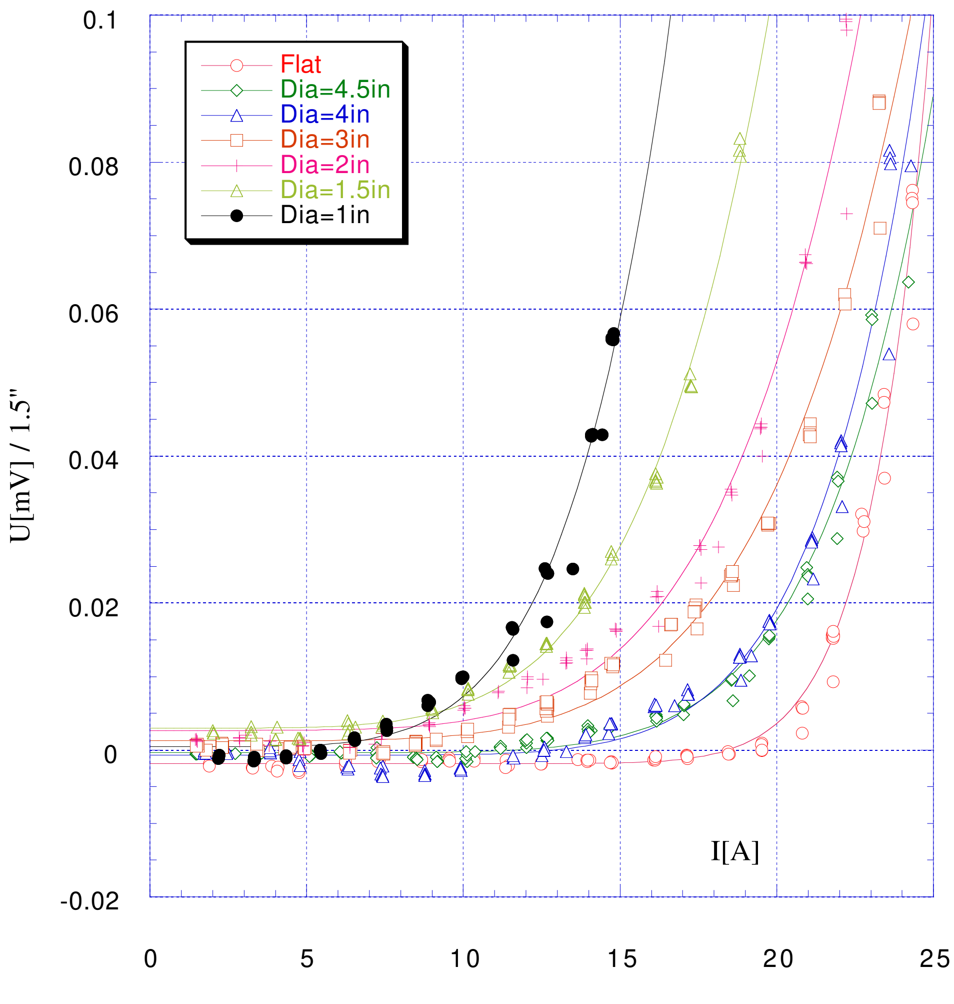

Figure 4: Sample S2, plain HTS conductor. Voltage between two taps of 1.5" apart versus flowing current for different bending radius.

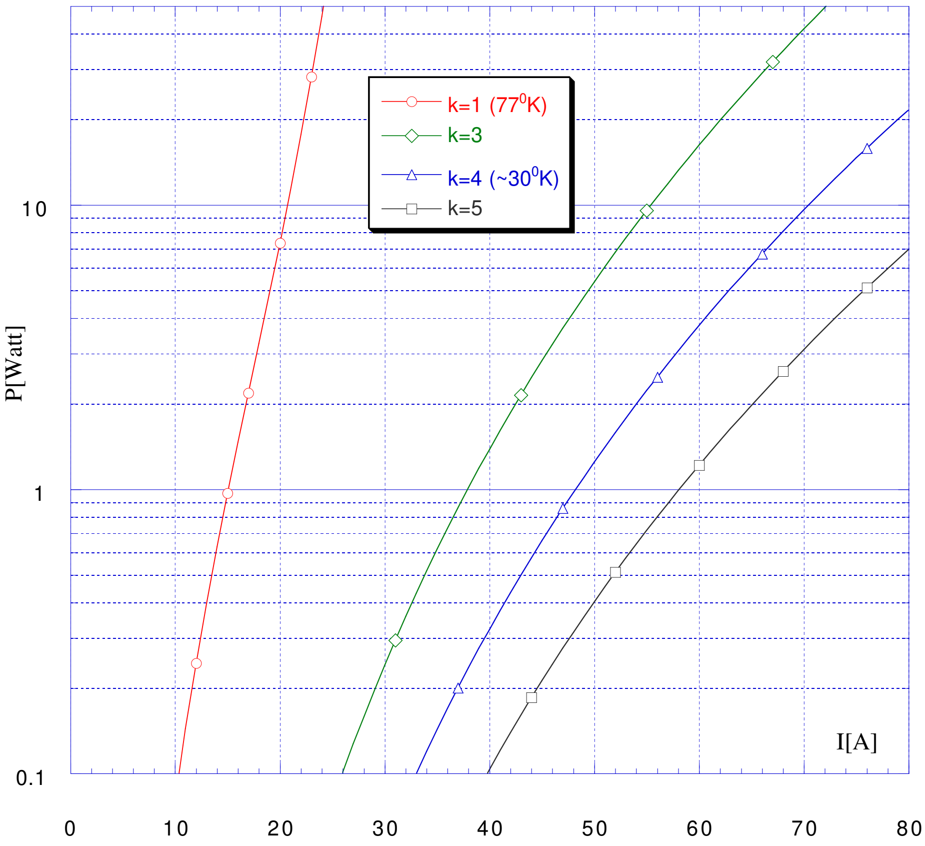

Figure 5: Power dissipated in HTS coils in one magnet as a function of current

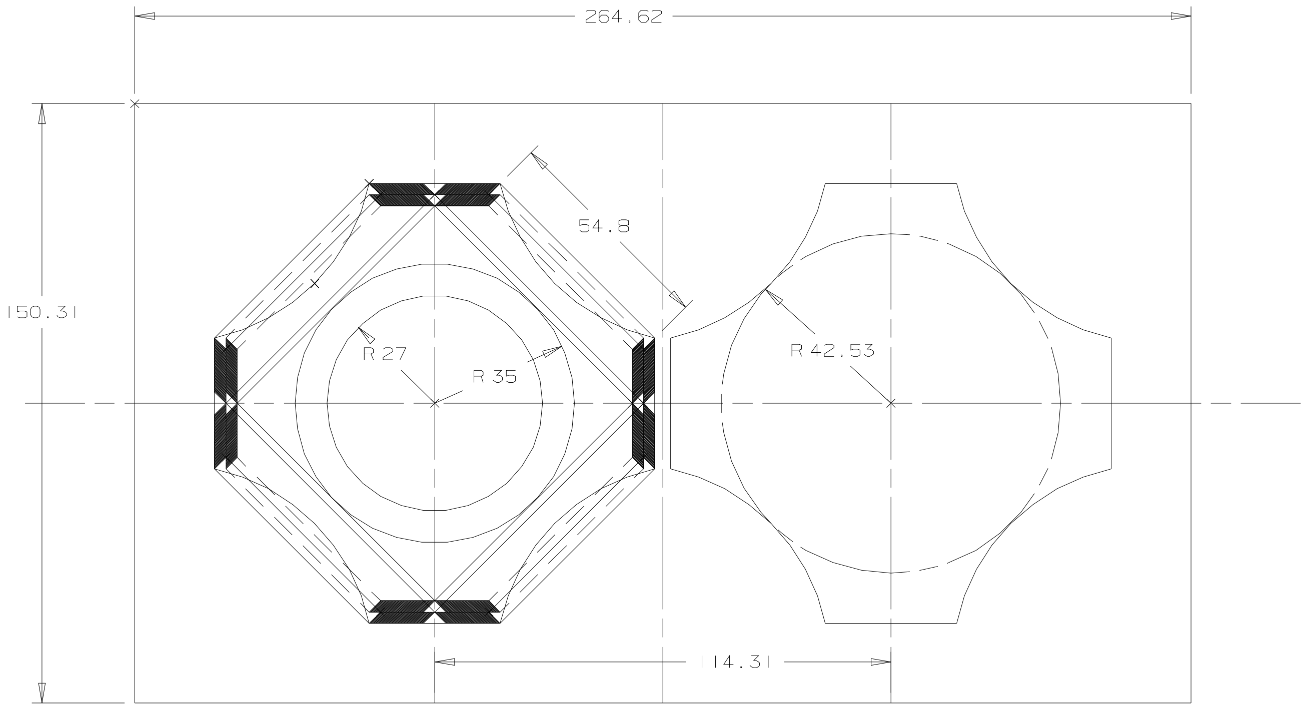

Figure 6: Schematic view of HTS version of CESR dual bore quadrupole magnet. Dimensions are given in mm

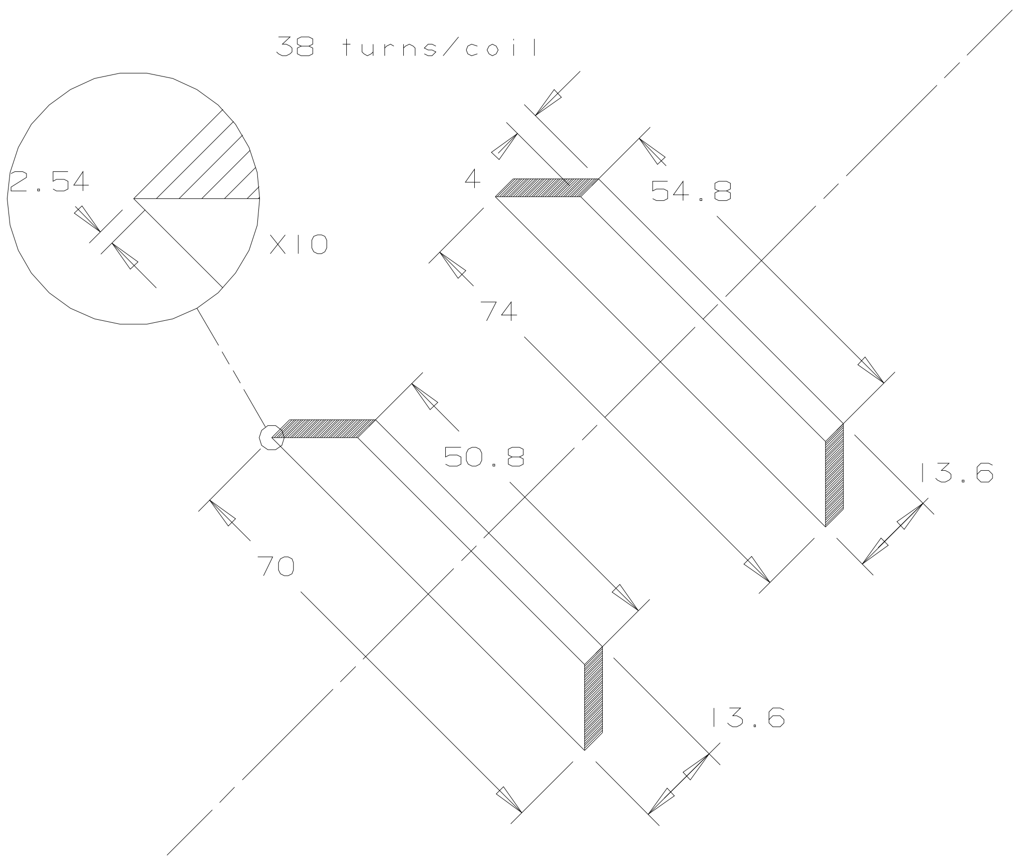

Figure 7: Schematic view of HTS coils. Dimensions are in *mm*.