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DEMAGNETIZE BOOSTER CHAMBER IN TPS

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Abstract

Taiwan Photon Source (TPS) project starts its booster commissioning starts from August 2014. Few issues have been discovered and fixed. Since the booster aperture is relatively small and number of magnets is barely sufficient. Therefore extreme precise control of booster chamber alignment and the corresponding chamber permeability is as well important.

In this paper, we present how the booster chamber is uninstalled, demagnetized and reinstalled within three weeks. This procedure is proven to result in the lowest booster chamber permeability in the world and a good high vacuum booster ring is built in 3 weeks.

INTRODUCTIONS

National Synchrotron Radiation Research Center (NSRRC) in Taiwan has just completed the construction of third generation synchrotron accelerator named Taiwan Photon Source (TPS) in second quarter of 2014, this 3GeV, 500mA designed energy machine will provide 48 beam lines in the future. The machine finished the Linac was commissioned in August 12, 2014 and the booster ring started its beam-based hardware testing right after that date.

However during the booster commissioning the operation group encountered several problems such as booster dipole magnet power overheated, even the power supply group quickly resolved the problem but the operation staff still had problem to store the beam in the 500m circumference concentric booster chamber. This 35mm x 20mm stainless steel 304 elliptical chamber was drawn from circular stainless steel tube and is 0.7mm thick, as shown in Figure 1.

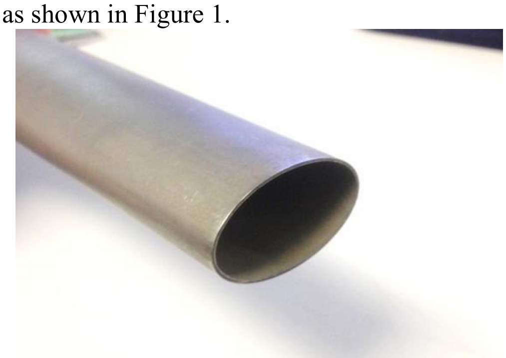

Figure 1: TPS booster chambers.

Beam dynamics staff had problem to fully control the electron beam even with correctors. Simulation shows that difference of closed orbit distortion (COD) can be up to $\pm 20\text{mm}$ without corrections. While everyone was wondering what might be the causes. In November 12, 2014, one of engineering staff found that elliptical chambers attracted his small piece of NdFeB magnet. We further discovered that the chamber does meet our low permeability requirement (typically magnetic relative permeability for stainless steel $\mu_r = 1.01$ and some of them was found to be $\mu_r = 1.8$!). This explains why operation staff failed to store the electron beam in the booster no matter how hard they have tried to tweak the magnetic fields.

Since the target schedule is planning to have beam stored in the storage ring by the end of 2014, we have to demagnetize the booster chamber as soon as possible. As a matter of fact, vacuum group has to remove total 500m long booster chambers, demagnetize, reinstall and pumping down in three weeks.

Table 1: Heat Treatment Material Processing to Demagnetize Metals

Process	Pros	Cons
Continuous heat treat furnace	▪ Large size	▪Non-uniform heating, large deformation. ▪Not clean.
Demagnetizer	▪ Convenient to use. ▪ Cost effective	▪Temporarily demagnetize but not permanent.
Vacuum furnace	▪ Compliance with UHV	▪Limited heat treatment sizes.

The demagnetization process is to heat up stainless steel to Austenite (γ) phase at elevated temperature. This heat treatment process is to re-transform Martensitic structure back to Austenitic one. The carbon composition of SST304 we procured is 0.06, and the suggested demagnetized temperature is $1050\ ^oC$ [1], then cool down to room temperature. As shown in Table 1, there are several processes to demagnetize the stainless steel. It is clear that vacuum furnace is the only way to go, except we have many long tubes which are over 2-4meters long. And most of domestic heat treat companies have only less than 1.2m maximum size furnace.

Another challenging of this demagnetization task is how to efficiently sort out all the elliptical chambers, and restore them back within the time frame.

DEMAGNITIZATION

Table 2 indicates the original quantity of the booster chamber with their corresponding flange-to-flange length range.

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Table 2: TPS booster tubes length

Range	quantity	Cut short?
Bending chamber (1.1m)	12	Cannot
Bending chamber (2m)	42	Cannot
Straight chamber[0, 1m]	24	No need
Straight chamber [1m, 4.5m]	103	Yes
Total	181	

After we carefully checked all the elliptical chambers, especially for those are longer than 1m, we found out most of them can be cut short in order to fit in 1m vacuum furnace. Furthermore, in November 17, we also realized that for those tubes not going through dipole, quadrupole and sextuple magnets can be replaced by 38mm OD (1.1mm thick) circular tube. This has big advantages:

1. It will gives electron bigger space for larger vertical dispersion.
2. Easier to align as it to elliptical tube.
3. 38mm Circular tube is industry standard and has been demagnetized.
4. Vendor fabricates those circular tubes and welds both flanges. It saves our time to focus only on demagnetization.

For those booster chamber lengths less than 0.6m, NSRRC has small vacuum brazing furnace which can be utilized for demagnetization. Therefore for straight elliptical chambers longer than 0.6m and shorter than 1m can be demagnetized in local vacuum furnace. The only elliptical chambers remain are dipole chambers. As shown in Table 2, we have 12 1.1m short dipole chambers and 42 2m long dipole chambers in the TPS booster ring, these dipole chambers cannot be cut short because they are embedded inside the booster magnets.

In the beginning we had no luck while looking for domestic vacuum furnace which can fit the booster chamber longer than 1.2m, not to mention we have 42 2m dipole chambers. One of the suggestions is to ship all these dipole chambers to SSRF because they have a 1.1m x 3.5m heat treatment furnace. The suggestion was turned down due to unpredictable time of customs clearance.

We found one heat treatment company in Taichung such that they are able to demagnetize the chamber up to 1.5m. We quickly shipped few sample tubes for testing. The result seems acceptable but the outer surface of the elliptical chamber becomes light green when it came out from the furnace. The inspection shows that the layer contains Cr and Mn. Even the experiment shows that it is demagnetized and also UHV compatible but we didn't feel comfortable with this demagnetize result due to its colouring. Nevertheless, their furnace is a vertical one which might lead to curvature change of the dipole chamber during heat treatment.

As we almost lose our hope, in November 29, we were told that a domestic heat treatment company named XHT (Xing Guang Industrial Co.) in Tainan has a 2.2m horizontal vacuum furnace which should be able to suit our needs. We ran to Tainan with few test samples and were proven to be better than we expected. In December 1, 2014, we brought total 104 tubes (including 54 bending chambers, 46 straight tubes, 2 spares) to XHT, the furnace is able to take 10~20 tubes per batch. In 35 hours the furnace ran 7 batches and delivered clean, shiny and demagnetized elliptical chambers as shown in Figure 2.

Figure 2: Booster chambers after they are demagnetized.

In the meantime total of 97 circular tubes had been fabricated and shipped to the lab in November 30, 2014. Each circular tube has its own specific length to accommodate with that of the original elliptical tube which had been cut short (see Fig. 3).

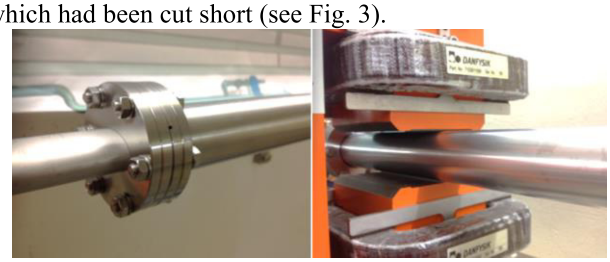

Figure 3: Left: elliptical chamber connected with circular chamber. Right: circular chamber goes through booster corrector magnet.

It took vacuum group one week to weld demagnetized chambers with flanges, vacuum clean all chambers including circular one, mount them together, align, pumping down and bake out. We also made some FRP blocks to retain the same precision for elliptical chambers as that of dipole, quadrupole and sextuple magnets.

The vacuum group connected the very last demagnetized booster chamber in November 10, as shown in Figure 4.

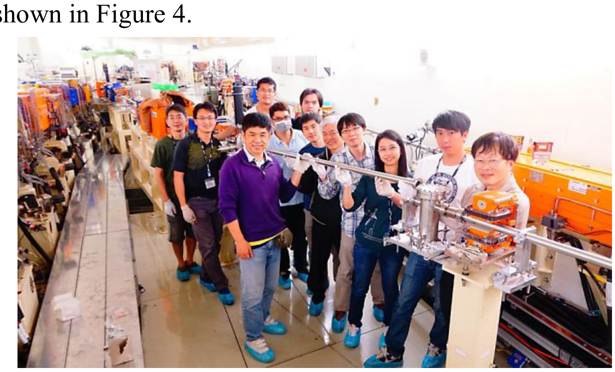

Figure 4: Vacuum group connect the very last booster chambers.

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We measured the permeability after demagnetized and found out it reaches $\mu_r = 1.002$ [2], which is five times better than regular one. Since most of elliptical chambers are demagnetized by vacuum furnace (heating up to 1050 ^oC) in TPS, Vacuum clean and bake out are omitted. The record also shows that the vacuum pressure goes down to 10^{-9} Torr in one week. Figure 5 illustrates the TPS booster vacuum pressure before demagnetization (August, 23, 2014) and after (December 24, 2014):

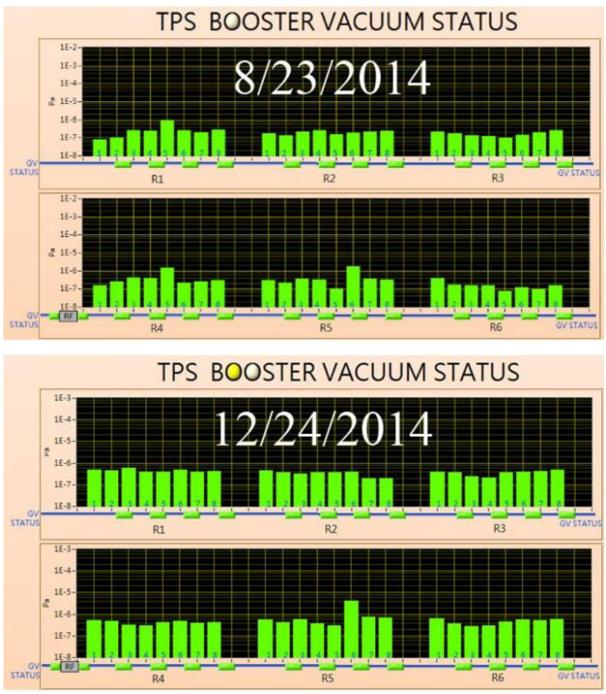

Figure 5: Booster vacuum pressure before and after demagnetization.

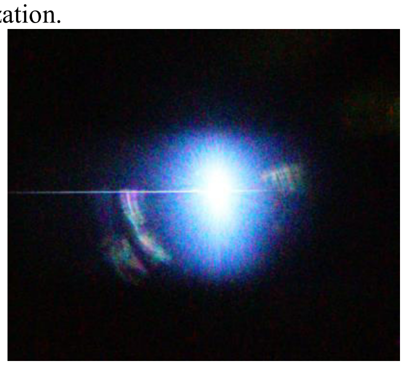

Figure 6: First synchrotron light from TPS storage ring.

Finally in December 31, 2014 TPS successfully stored the beam. Figure 6 is the first synchrotron light seen at the end of visible view port of TPS diagnostic front end (FE40). In addition, before Chinese New Year of 2014 (January 15), operation staff has successfully delivered 3GeV, 50mA electron beam in the storage ring. Currently, TPS has reached 100mA stored beam and is undergoing insertion device installation.

Table 3 summarizes the milestones of this demagnetization task:

Table 3: Milestones of TPS Booster Demagnetization

Date	Milestone
11/13	Find elliptical booster chamber has high permeability.
11/17	Remove all booster chambers. Decide to cut long elliptical chamber and replace with circular one.
11/18	Procure circular tubes with flanges.
11/21	Laser cut straight booster chamber and vacuum clean.
11/25	Prove bending chamber (1.2m) won't deform after demagnetization.
11/28	Receive all circular tubes. Vacuum clean.
12/1-12/2	Demagnetize rest of 100 chambers which including straight and bending ones.
12/2-12/6	Reinstall elliptical chambers, circular tubes and alignment.
12/7-12/10	Pump down and leak check.
12/31	Store beam at 3GeV, 1mA.

CONCLUSIONS

TPS is the first synchrotron accelerator project which seriously demagnetizes the stainless steel vacuum chamber to the extreme so that it dramatically reduces the extra steering error during beam commissioning. As to demagnetize elliptical chamber, we also found out even without vacuum cleaning and baking out after booster chamber is installed, the vacuum pressure still quickly reaches to the previous magnitude. The reason is during heat treatment, the chambers experience high temperature 1050 ^oC , and there is no need to perform any extra vacuum cleaning. Thus we can almost conclude that demagnetization process not only provides us a demagnetized vacuum chamber but also saves the post vacuum cleaning as well as baking out time.

ACKNOWLEDGEMENT

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