MAGNETIC FIELD MEASUREMENT SYSTEM OF CS-30 CYCLOTRON

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Abstract

The magnetic field of the CS-30 Cyclotron at King Faisal Specialist Hospital and Research Centre (KFSHRC) has been measured using Hall probe-based mapping system. Although the CS-30 Cyclotron was under full operation for 3 decades, yet, it was crucial to evaluate the stability of beam orbits and also to study the low extraction efficiency, particularly after stripping the cyclotron coils and its three sectors. The rational for stripping magnetic component was to replace the pole tip seal underneath the frame.

The Hall probe was mounted on a high precision X - Y stage, which was driven by three stepping motors, two motors for Y - axis and a motor for X - axis. The 3MH5 digital Tesla-meter is a high performance magnetic field measuring instrument, based on the Hall Effect magnetic field to voltage transducer. It has digital data correction to provide 0.01% accuracy and it provides the possibility of automatic data acquisition via USB port of our computer.

In this paper, a Hall probe mapping system and the results of the magnetic measurement of the CS-30 magnet are described.

INTRODUCTION

The CS-30 cyclotron at King Faisal Specialist Hospital and Research Center (KFSHRC) has been operating since 1982 for production of radioisotopes, such as ^{18}F and ^{15}O for positron emission tomography applications [1].

Some cyclotrons, including the CS-30 at KFSHRC, contain sets of harmonic coils, also called trim coils, arranged to supply a weak field that acts as a magnetic pump and enhances the main magnetic field in the central region and in the extraction region. Depending on the polarity of the electric current applied to those coils, they can generate a positive field, enhancing the main magnetic field, or a negative one (in the opposite direction) which weakens the main field slightly.

Additionally, cyclotrons have an extraction system, comprising the equipment that extracts the beam from the accelerated region to the main beamline of the cyclotron. In negative ion cyclotrons (whose accelerated particles are negative ions), this is done by stripping electrons from the negative ions using carbon foils [2]. In positive ion machines, the mechanism is more complicated, consisting of an electrostatic deflector (which has two parts: a septum made of tungsten, held at zero potential, and a high voltage electrode) and a magnetic channel to eliminate the magnetic field effect of the extracted beam. On the last rotation, particles experience a strong electric field capable of modifying slightly the trajectory of their orbit.

The magnetic field of CS-30 magnet was measured using the Hall mapping method described in [2-6]. For measurement of cyclotron magnets, the Hall probe mapping system at many laboratories use the polar coordinate system [2-4]. It is mounted on a high precision x–y stage, which is driven by a stepping motor at end of the Hall probe carrier, and maps the magnetic field in the polar coordinates. The system used the **'flying mode'** field-mapping method in which the data acquisition is made while the Hall probe moves [4]. The requirements of the field measurement system for CS-30 are listed in Table 1.

Table 1: Specifications of the Mapping System

System specifications &Unit	Value
X scan capability (mm)	1000
Y scan capability (mm)	1000
Mechanical resolution (μm)	1
Range of magnetic field (T)	2
Relative error for $\langle B(r) \rangle$-measurement (%)	0.01

HALL MAPPING SYSTEM

The teslameter and Hall probe have been used widely to measure the magnetic fields of cyclotrons. The 3MH5 digital teslameter is a high performance magnetic field measuring instrument, based on the Hall effect magnetic field-to-voltage transducer (Hall probe). It has digital data correction to provide 0.01% accuracy and it provides the possibility of automatic data acquisition via a USB port. The Hall probe is mounted on a high precision X-Y stage driven by three stepping motors, one for the x-axis and two for the y-axis. The stepping motors are run by a 3-axis stepper controller/driver (TMCM-3110). Time resolution of the x-axis and y-axis can reach up to 25 and 34 μm respectively. The time resolution of the Hall probe is 100 ms; however, measurements were taken every 200 ms. The Hall probe has a built-in temperature sensor to compensate for variation in temperature.
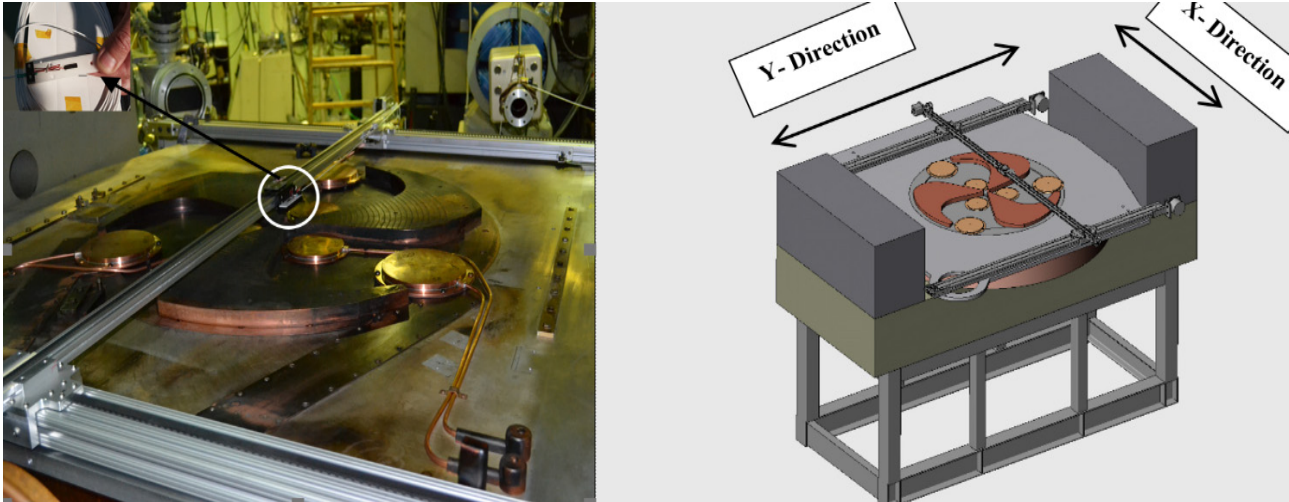
Figure 1: The setup of the magnetic mapper inside the region of interest (A 3D model of the CS-30 is shown to the right). The accelerated area in the CS-30 cyclotron is 96 cm.

A graphical user interface (GUI) was developed to control the measurement of the magnetic field using Lab-VIEW software, a graphical environment for the development of sophisticated measurement and control systems using intuitive graphical icons and wires that resemble a flowchart. Figure 2 shows a snapshot of the GUI; its motor controller is to the right. The software itself has many advantages, including the continuous saving of the acquired data in external memory. Additionally, it draws 3D graphs of the magnetic field while acquiring the data. The mapping system has the further advantage of measuring the magnetic field in both polar (r, Ø) and x-y coordinates. In polar form, it collects the values radially in steps of 0.5 cm (the total radius is 51 cm) every 1° for a total of 360°. Thus, the total number of points collected was 36,720. In x-y coordinates, the motion step was 0.5 cm in the x and y-directions.
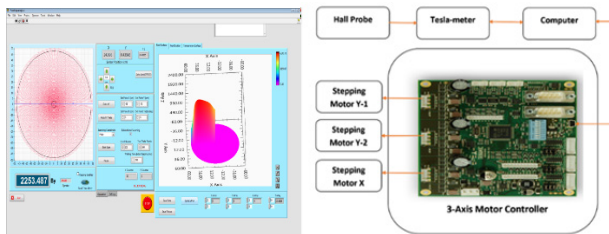

Figure 2: LabVIEW-based software to collect magnetic field values and its axis controller.

FIELD MEASUREMENT RESULTS

The result of Hall probe mapping for the CS-30 cyclotron magnet at an excitation current of 326 A is shown in Fig. 3. This figure shows a typical profile of a magnetic field for a cyclotron magnet. The measured magnetic field at the hills and valleys are ~2.2 and 1.4 T respectively. This measured field data in Cartesian coordinates have been converted into the field data in the polar coordinates for the equilibrium orbit calculation. For the data calcula-

tion the following mesh points in cylindrical coordinates were chosen as:

$$r_k = 5k \text{ mm}; k = 0, 1, 2, 3, \dots, 51$$

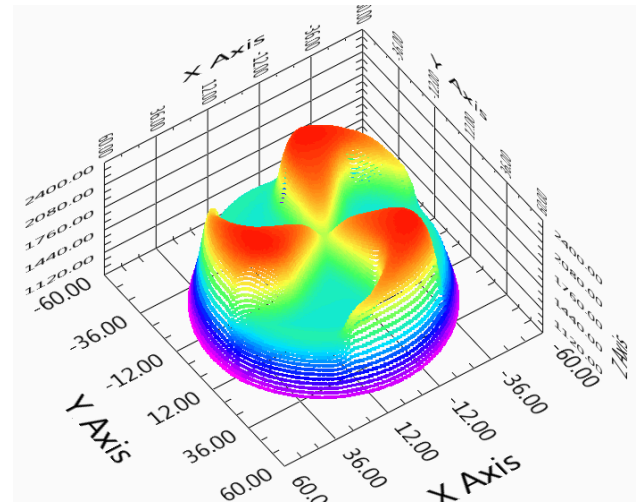$$\theta_l = l^0, l = 0, 1, 2, \dots, 359$$

Figure 3: A profile of measured magnetic field of the CS-30 cyclotron.

Figure 4 shows the average magnetic fields along the equilibrium orbits. it also shows that the average magnetic field increases slowly along the radius in accordance with the isochronous equation:

$$w = \frac{q <B(r)>}{\gamma(r)m_0} \tag{1}$$

where w is the cyclotron frequency, q is the particle charge, $< B(r >$ is the average magnetic field, the relativistic factor $\gamma(r)$ increases with the radius, and m_0 is the rest mass of the particle.
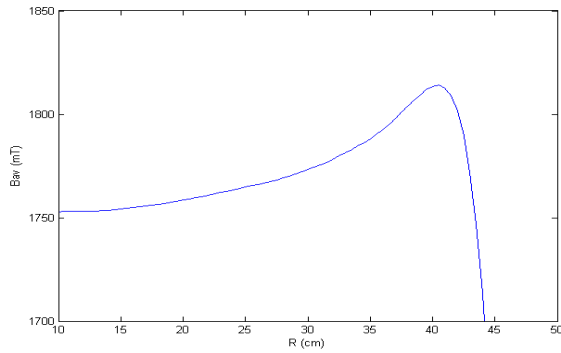
Figure 4: The average magnetic field along the equilibrium orbit as a function of the radius.

Figure 5 shows the computed radial focusing frequency based on the measured magnetic field. And this figure shows that between R =10 cm and around 40 cm, v_r is above the $v_r = 1$ resonance. However, around $R = 10$ cm, the beam passes through the $v_r = 1$ resonance. This is due to the small field bump applied near the center, as mentioned above. However, it is not so harmful to the beam because the beam passes through this resonance quickly. Near the extraction region, there is also $v_r = 1$. Figure 6 Shows that the average v_z is about 0.48, but particle crosses the $v_z = 0.2$ resonance near $R = 10$ cm.
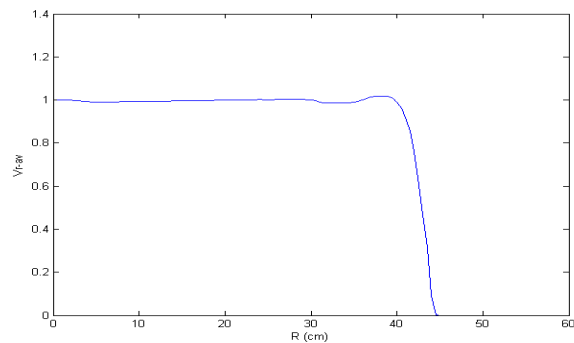

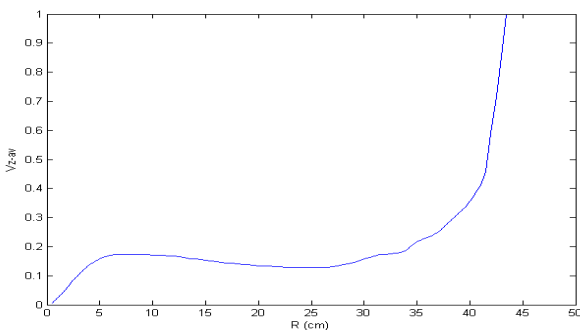Figure 5: Radial focusing frequency as a function of the radius.

Figure 6: Vertical focusing frequency as a function of the radius.

CONCLUSION

The Hall probe mapping system provides accurate measurement. The maximum field obtained is 2.2 T and the average is 1.8 T. The average magnetic field error along the beam orbit is less than 0.015%.

ACKNOWLEDGEMENT

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