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The Effect of Seed Distance on the Lateral Guidance Force of Multi-Seeded YBCO Superconductors

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Abstract – High temperature superconductors (HTSs) have been widely used in magnetic bearing systems, magnetically levitated transportation systems (Maglev), superconducting motors, etc. due to their stable levitation properties. Although the studies on Maglev systems have been increasing in recent years, both the vertical levitation and lateral guidance forces are not at desired level for technological applicability of these systems. Furthermore, the studies have been mostly focused on enhancing the levitation force rather than the guidance force. One of the ways to improve the levitation and guidance forces of Maglev systems is improving the superconducting properties of HTSs and/or producing HTSs in larger single domains and in large geometries. The most effective method to produce HTSs in larger single domain within a reasonable production time is the multi–seeded melt growth (MSMG) method. However, it can be seen from the studies in literature that the increasing seed number on HTSs corrupts the superconducting properties of MSMG samples. One can overcome this negation by changing the number, orientation and distance of the seeds. In this study, we have produced cylindrical YBCO superconducting samples with different distance of seeds by MSMG method and investigated the effect of seed distance on the lateral guidance force both in zero field cooling (ZFC) and field cooling (FC) regimes at different measurement temperatures of 77 K, 80 K and 83 K. The results showed that the movement stability of Maglev systems can be increased by changing the distance of the seeds in HTSs.

Keywords – *Multi-seed, YBCO, Guidance force, Seed distance.*

I. Introduction

The unique stable levitation or suspension properties of high temperature superconductors (HTSs) above or below a permanent magnet (PM) make them useful in various applications such as contactless magnetic bearings [1], magnetically levitated transportation (Maglev) [2-5] and flywheel energy storage systems [6], etc. Although there are many studies in literature on Maglev transportation systems [7-10], the magnetic levitation force and magnetic guidance force values are not at desired level for practical applicability of these systems. Vertical magnetic levitation force and lateral guidance force should be increased for loading capacity and stability of Maglev systems, respectively. To accomplish this situation, there are several methods such as optimizing the permanent magnetic guideway (PMG) [11,12] and enhancing the superconducting properties of HTSs. The dimensions of HTSs should be as large as possible for technological applicability of Maglev systems. The researchers have used top–seeded–melt–growth (TSMG) (RE)BCO (RE= rare earth element, generally Y or Gd) superconductors [13,14] in Maglev systems because of high critical current density and flux trapping capability of these superconductors. However, the TSMG method is not efficient enough due to the limitations such as high cost, long processing time and limited sample dimensions. Therefore, this method was modified and multi–seeded–melt–growth (MSMG) method were developed by using more than one seed on the sample [15,16]. Although the MSMG method has some advantages, it also has some disadvantages such as decrement in magnetic force properties with increasing SmBaCuO seed number and distance between the seeds. This decrement in magnetic properties such as magnetic levitation and guidance force, trapped magnetic flux etc. is attributed to the existing of non−superconducting residual melt (CuO and BaCuO2) at grain boundaries between the seeds [17,18]. Although there are studies related to changing the distance, orientation and angle between the seeds [18,19], there is no detailed study on the effect of seed distance on the guidance force of MPMG samples at different measurement temperatures. Therefore, we have produced YBCO samples in cylindrical geometry with different seed distances by using MSMG method and investigated the effect of seed distance on the guidance force performance of the samples in different cooling regimes of FC (field cooling) and ZFC (zero field cooling) and at different measurement temperatures of 77 K, 80 K and 83 K.

II. Materials and Method

In this study, the $YBa_2Cu_3O_7$ (Y123) samples were fabricated with multi–seeded–melt–growth (MSMG) method with cold seeding technic. Y123 superconductor and Y211 (Y2BaCuO6) non−superconductor phases were prepared using Y_2O_3, $BaCO_3$ and CuO powders and calcinated at 900 °C for 20 h and 920 °C for 15 h, respectively, by solid−state reaction method. The powders of Y123, Y211 and CeO_2 were mixed at weight ratios of 75 %, % 25 and 5%, respectively and prepared powder mixture with 30.15 g was pressed in a steel mold into the cylindrical pellets of 32 mm in diameter. The NdBaCuO seeds were placed on the top of the Y123 pellets to make a (100)/(100) grain junction with two seeds and the c−axis of the NdBaCuO seeds normal to the top surface of the YBCO pellets. The distance between the seeds was varied as 1, 4 and 12 mm to investigate the effect of seed distance on the magnetic guidance force and the samples were named as MS01, MS04 and MS12, respectively. The final dimensions of the seeded YBCO pellets after the sintering and oxygenation process were determined with diameter of 26 mm and height of 8 mm and detailed fabrication procedure can be found in [13]. The photo of one of the samples after calcination and oxygenation process is given in Fig. 1.

Fig. 1. The photo of two−seeded cylindrical YBCO superconductor fabricated by MSMG method

Lateral guidance force (F_x) measurements depending on lateral distance (x) between the sample and permanent magnet were carried out using the Magnetic Levitation Force Measurement System (MLFMS), designed by Sukru Celik and financially supported by The Scientific and Technological Research Council of Turkey (TUBITAK) with project number of 110T622. The MLFMS system (Fig. 2) consists of a stainless steel vacuum chamber, close cycle cryostat, high vacuum pumping system three dimensional movable axes and three axis load cell. The detailed information about the MLFMS system can be found in [20].

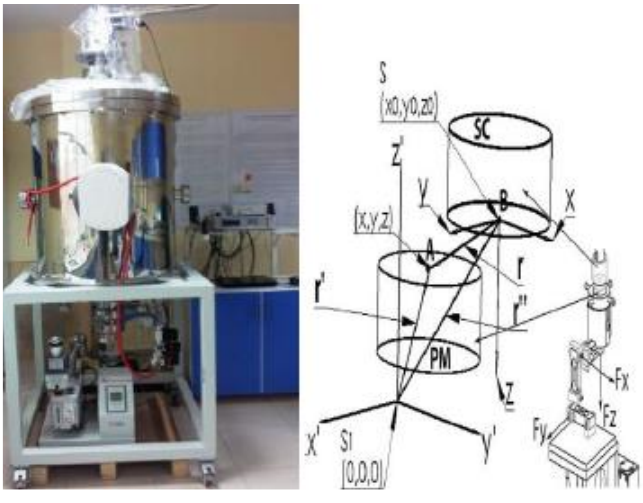

Fig. 2. The photo and schematic diagrams of magnetic levitation force measurement system.

The guidance force measurements were performed in different cooling regimes of FC (field cooling) and ZFC (zero field cooling) and at different measurement temperatures of 77 K, 80 K and 83 K. In FC measurements, the vertical distance between the YBCO sample and the PM was fixed as 1.5 mm while the cooling the sample to the measurement temperature. After the cooling, the lateral distance between the top centers of the sample and the PM was changed from x=0 mm to x=50 mm, then from x=50 mm to x=-50 mm and finally from x=-50 mm to the x=50 mm. The lateral guidance force data were collected via a software during the lateral movement of the sample. In ZFC measurements, the vertical distance between the sample and the PM was fixed as 50 mm, meanly the sample was cooled in the absence of magnetic field. After the cooling, the sample moved vertically down to the measurement height (MH) of 1.5 mm and then the measurements were performed similar to that in FC regime. The measurements were carried out at different temperatures of 77 K, 80 K and 83 K.

III. RESULTS

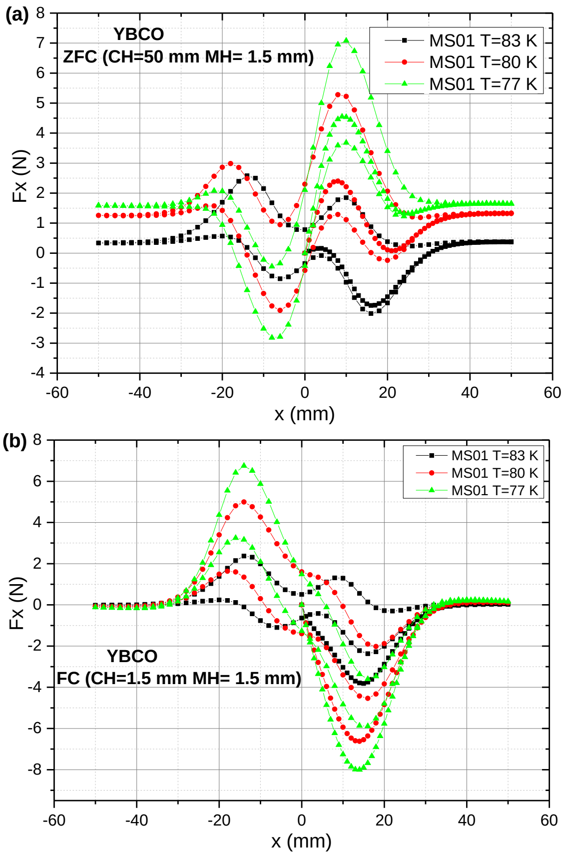

Fig. 3. Lateral guidance force curves (F_x) of MS01 sample as a function of the lateral position (x) in (a) ZFC regime and (b) FC regime, at different measurement temperatures

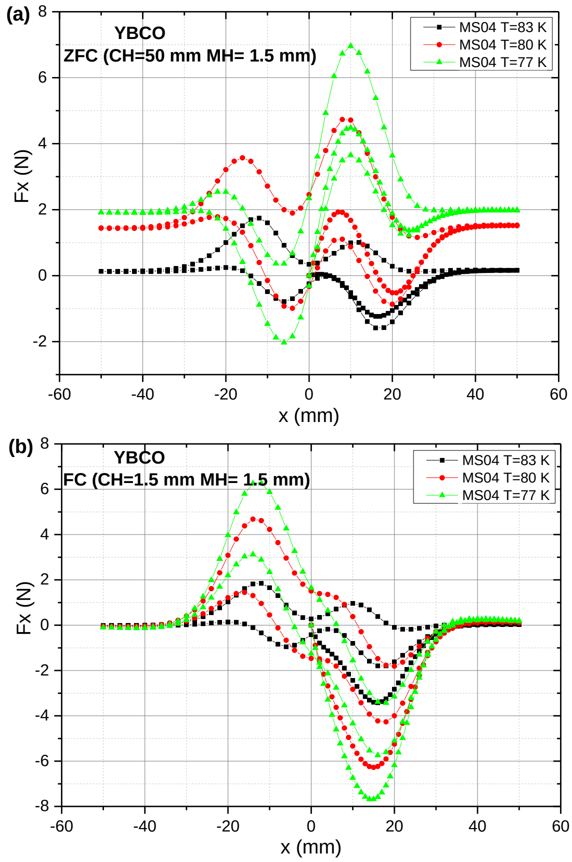

Fig. 4. Lateral guidance force curves (F_x) of MS04 sample as a function of the lateral position (x) in (a) ZFC regime and (b) FC regime, at different measurement temperatures

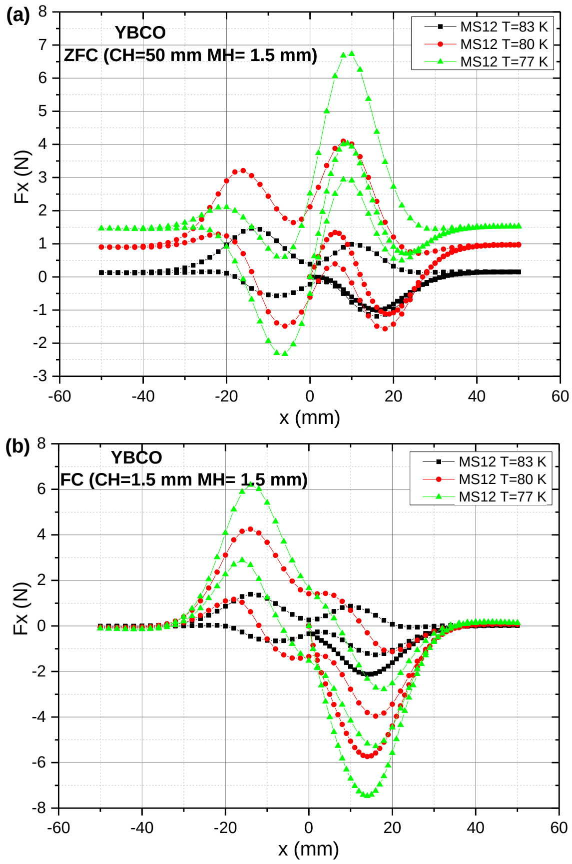

Fig. 5. Lateral guidance force curves (F_x) of MS12 sample as a function of the lateral position (x) in (a) ZFC regime and (b) FC regime, at different measurement temperatures

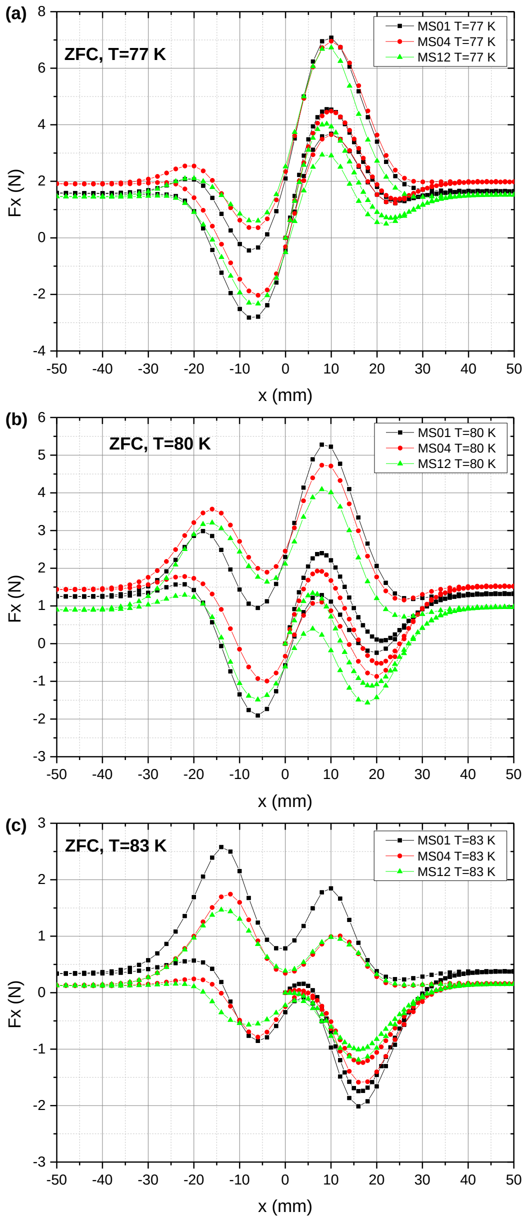

Fig. 6. Lateral guidance force comparison of samples with different seed distances in ZFC regime, at the measurement temperatures of (a) 77 K, (b) 80 K and (c) 83 K

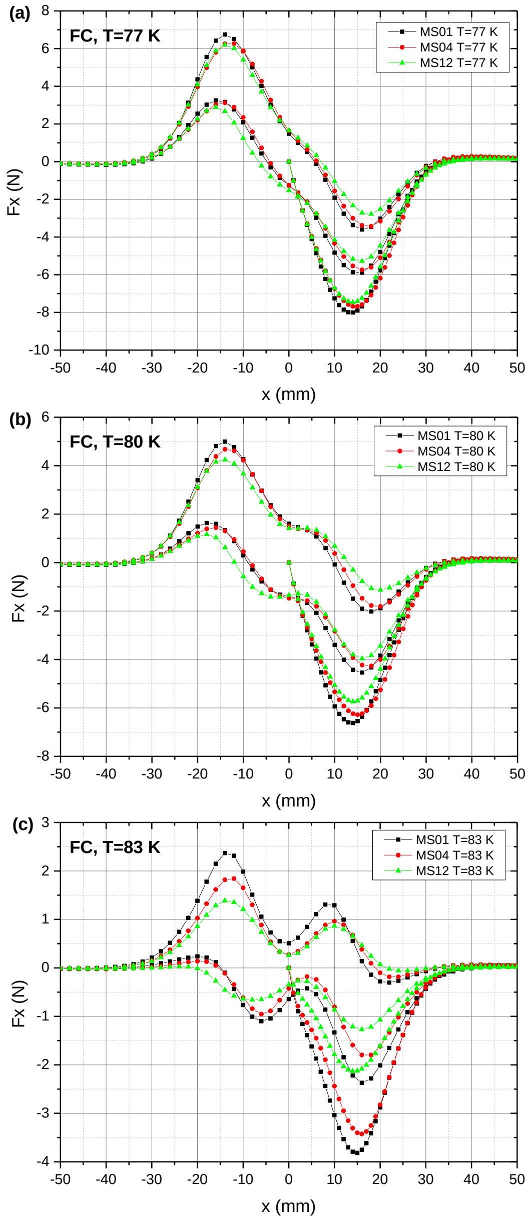

Fig. 7. Lateral guidance force comparison of samples with different seed distances in FC regime, at the measurement temperatures of (a) 77 K, (b) 80 K and (c) 83 K

IV. DISCUSSION

Fig. 3 shows lateral guidance force curves (F_x) of MS01 sample as a function of the lateral position (x) in different cooling regimes of ZFC and FC, at different measurement temperatures. It is clear from this figure that the guidance force increases with decreasing measurement temperature due to the increment in superconducting properties of the sample at the temperatures far from the critical temperature (T_c). It is seen by comparing the Fig. 3a and b that although the repulsive part (the positive force values) of the guidance force curve in ZFC regime is bigger than that in FC regime, the attractive part of the curve in FC regime is bigger than that in ZFC regime. This is attributed to the fact that the trapped flux inside the superconducting sample increases with decreasing cooling height.

Lateral guidance force curves (F_x) of MS04 and MS12 samples as a function of the lateral position (x) in different cooling regimes of ZFC and FC, at different measurement temperatures are shown in Fig. 4 and Fig. 5, respectively. One can see from these figures that the maximum values of guidance force curves increase with decreasing measurement temperatures as consistent with Fig. 3. It is also seen in these figures that the attractive part of the curves is bigger and repulsive part of the curves is smaller in FC regime than in ZFC regime, similar to the curves of MS01 sample.

Fig. 6 shows the lateral guidance force comparison of samples with different seed distances in ZFC regime, at different measurement temperatures. One can see from this figure that when the samples move laterally relative to the centre of the PM to the right direction, the lateral force increases and shows a repulsive character especially at T=77 K and T=80 K. This is attributed the diamagnetic character of the sample in ZFC regime. However, it can be seen in Fig. 6c that this diamagnetic behaviour of the sample diminishes at the measurement temperature of 83 K which is close to the T_c.

The lateral guidance force comparison of samples with different seed distances in FC regime, at different measurement temperatures is shown in Fig. 7. It is clear from this figure that when the samples move laterally relative to the centre of the PM to the right direction, the lateral force decreases and shows an attractive character and this character gets weaker with increasing temperature. The attractive character of guidance force curves indicates the stability of Maglev system. One can see from Figs. 6 and 7 that both the repulsive and attractive lateral force values increase with decreasing distance between the seeds.

V. CONCLUSION

In this study, we have fabricated two–seeded cylindrical $YBa_2Cu_3O_7$ (Y123) samples with multi–seeded–melt–growth (MSMG) method with cold seeding technic and investigated the effect of the seed distance on the lateral guidance force of multi–seeded YBCO superconducting samples. The lateral guidance force measurements were performed in both cooling regimes of FC and ZFC and at different measurement temperatures of 77K, 80 K and 83 K. It was found that both the repulsive and attractive parts of guidance force curves enhance with decreasing temperature and decreasing distance between the seeds.

It is concluded from this study that the stability of Maglev systems can be increased by adjusting the seed distances of superconducting samples and it is believed that this study will make a significant contribution to the technological applicability of Maglev systems.

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