Development Of Ferrite-Based Permanent Magnet for Water Meter Linflow in Bandung

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Abstract

A simple application of permanent magnet is flow measurement or the water meter manufactured by PT. Multi Instrumentasi located at Ujung Berung, Bandung. Collaborative efforts in permanent magnet technology transfer, industrial manufacturing test, and the application of the technology in water metering form an integrated sequence. Permanent magnets (barium hexaferrite, BaO.6Fe2O3) are manufactured by a series of powder preparation, molding, sintering, and magnetization. Manufacturing results of the permanent magnet sintered at 1280 °C indicate that single-phase hard magnetic BaO.6Fe2O3 has been formed, exhibiting a crystal size of ≤3 μm with a non-homogenous grain distribution and numerous pores. Remanence Br of 2160 Gs and coercivity Hc of 3215 Oe are obtained, whereas the Br and Hc of the commercial products are 2560 Gs and 941 Oe, respectively. The permanent magnet BaO.6Fe2O3 sintered at 1280 °C has a density of 4.43 g/cm³, whereas the commercial products have a density of 5.3 g/cm³. The magnetic products need to be tested on the water meter manufactured by PT. Multi Instrumentasi to evaluate the reliability of the results.

Keywords: water flowmeter, barium hexaferrite, sintered density, remanence, coercivity

1. Introduction

Magnetic materials are advanced materials that are considered essential in automotive, electronic, and energy applications. Magnetic materials are generally divided into two groups, namely, soft and hard [1-2]. Some developed countries use magnetic materials in electron spin resonance, for magnetic levitation in fast trains, particles accelerator, anti-lock braking systems, motor, sensors, microwave shielding, mechatronics, and magnetic resonance imaging instruments[3-6].

Laboratory-scale studies on magnetic materials have been conducted by various non-ministerial government institutes and universities in Indonesia; however, the results of such studies have remained industrially inapplicable. All research activities have thus far been focused on new materials engineering or new methods relevant to technological development.

A simple permanent magnet application is the magnet used in water meters manufactured by PT. Multi Instrumentasi located in Ujung Berung Bandung, Indonesia. With products from Lembaga Ilmu Pengetahuan Indonesia (LIPI) or Indonesian Institute of Sciences research products, this private company has been producing permanent magnets based on water meters, such as the multi-test type. Permanent magnets were first used in Linflow water meters licensed under OKK Corporation-Japan in 1981. This product is generally used as a magnetic actuator directly applying the working principles of
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a multi-jet meter. However, the absence of an industry producing permanent magnets in the domestic market has led PT. Multi Instrumentasi to import such products from China for industrial use.

An Indonesian magnet consortium, which is a collaboration of private sectors, universities and research institutes, was founded in 2012. The association aimed at pioneering the domestic production of permanent magnets. Among the members of the consortium are Puslit Fisika LIPI, Pusat Penelitian Elektronika dan Telekomunikasi LIPI, Pusat Teknologi Bahan Industri Nuklir BATAN, Universitas Indonesia, and PT Sintertech, considered co-partners in permanent magnet production. The cooperation in the permanent magnet technology transfer from laboratory scale to industry scale requires a testing instrument for industrial purposes; a water meter produced by PT. Multi Instrumentasi Bandung was selected.

This paper discusses the development of ferrite-based permanent magnets for use in a water meter instrument produced by PT. Multi Instrumentasi Bandung, conducted by the Indonesian magnet consortium. The microstructure, density, and magnetic characteristics of ferrite permanent magnets are also discussed, and the results are compared with the characteristics of the standard magnet used by PT Multi Instrumentasi Bandung.

2. Theoretical Basis

A magnetic flowmeter or a water meter device uses a magnet to determine the water volume passing through a pipe. The water inside the magnetic flow meter, which electrical conductivity through the magnetic field, produces a voltage signal, which is then received by an electrode. When water flow increases, voltage is also increased; thus, the water flow becomes parallel to the voltage produced. A magnetic flow meter can be used for any fluids possessing an electrical conductivity >5 S/cm. The use of fluid with low electrical conductivity, such as deionized water, boiler feed water, or hydrocarbon, can result in instrument not functioning properly. The instrument can also be used for littered water or corrosive and abrasive fluids [7-8].

The water meter manufactured by PT. Multi Instrumentasi Bandung is a multi-jet meter. This meter works on multiple ports (holes) around the measuring chamber to produce a jet of water against the impellers. The impeller rotation speed is in relation to the velocity of water flow through the chamber. Magnet and gears change the number of rounds into the volume shown in the display register.

This meters have several advantages, including tend to be stable to changes in pressure, resistance to dirt, and resistance to magnetism values > 2500 Gs. This type of water meter is also more economical than the class C meter.

3. Methodology

The permanent magnet used in the water meter produced by PT. Multi Instrumentasi Bandung is based on Ba/S-ferrite with a strong surface magnet value ranging from 600 Gs to 950 Gs. On the basis of these characteristics, magnet production requires the following as main raw materials: barium carbonate, strontium carbonate (SrCO3), hematite, silicon dioxide additives, and adhesive material polyvinyl alcohol. The technological process of magnet production involves the following procedures: powder preparation, weighing the adjusted composition, thermal analysis, and characterization of mixtures of raw materials by differential thermal analysis (DTA). In accordance with the DTA curve, the temperature and calcination are determined. The microstructure of the calcined powder is further analyzed by X-ray diffraction (XRD) to determine the formation of phases. Grain size and grain distribution are observed by scanning electron microscopy (SEM). The powder is further pulverized using a ball mill for 30 h and then sieved until a 400-mesh is achieved. The next step consists of molding a magnet sample into a ring with an outer diameter of 8 mm, an inner diameter of 4 mm, and a thickness of 3 mm, pressed with a power 30 ton/cm². After sample formation is completed, the material is sintered at 1280 °C for 2 h. To determine the magnetic properties of the sample magnetization process needs to be done by giving an external magnetic field as much as 1 tesla. The characteristics of the permanent magnet are measured, PERMAGRAPHER C (Magnet Physics) is used to measure B-H
The flow chart of permanent magnet barium hexaferrite (BaO.6Fe2O3) manufacturing and testing are shown in Figure 1.

**Figure 1:** Flow chart of production of permanent magnet barium hexaferrite and its characterization

The permanent magnet used in the multi-jet water meter is ring-shaped. The sintered shape with a smooth surface is shown in Figure 2. The type-B water meter installed outdoors and its specification are shown in Figure 3 and Table 1, respectively.

**Figure 2:** Ring Shaped Permanent magnet used in water meter produced by PT Multi Instrumentasi Bandung. a). Design and b). Shaped and sintered product

**Figure 3:** The photo of Multi jet type Water Meter.
3. Analysis and Results
The production of the permanent magnet BaO.6Fe₂O₃ by the solid–solid mixing method reveals that the XRD pattern in the calcinated sample at 800 °C shows two phases; the dominant phase BaO.6Fe₂O₃ and the minor phase Fe₂O₃ shown in Figure 4(a). At 800 °C, 61% of BaO.6Fe₂O₃ and 39% of Fe₂O₃ with the minor phase of Fe₂O₃, the product tends to become a soft magnet. If the sintering temperature is raised to 1280 °C, only one single phase of BaO.6Fe₂O₃ is observed, as shown in Figure 4(b).

![Diffraction pattern in the sintered sample of barium hexaferrite magnet, a) at 800 °C and b) at 1280 °C.](image)

Qualitative and quantitative analyses of the phases in the sample measured by XRD and the XRD profile were analyzed using a General Structure Analysis System (GSAS) (Rietveld Analysis) software and then compared with the International Centre for Diffraction Data (ICDD) file. Table 2 shows the lattice parameter on the BaO.6Fe₂O₃ phase using GSAS or ICDD file and the density measured using the Archimedes method.
Table 2: Lattice parameter and phase of the barium hexaferrite powder

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<th>Lattice Parameter [nm]</th>
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<tr>
<td></td>
<td>GSAS (Rietveld Analysis)</td>
<td>ICDD file</td>
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<tr>
<td>barium</td>
<td>$d_0 = 0.5889$</td>
<td>$d_0 = 0.5892$</td>
</tr>
<tr>
<td>hexaferrite</td>
<td>$c_0 = 2.321$</td>
<td>$c_0 = 2.3183$</td>
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Figure 5 shows the SEM observation of the BaO.6Fe₂O₃ magnet sample. The SEM images reveal that relative particles < 3 μm in size with a less homogeneous distribution due to pores remain visible (dark area). To complete this microstructure analysis, transmission electron microscopy must be conducted.

![Image](image_url)

Figure 5: Diffraction pattern in the sintered sample of barium hexaferrite magnet.

The test result of the BaO.6Fe₂O₃ magnet sintered at 1280 °C and measured using a Magnet-Physik Dr Steingroever GmbH Permagraph C was determined to have a remanence Br of 2160 Gs and coercivity Hc of 3215 Oe, as shown in Figure 6. This value generates a relatively larger B-H curve because of the formation of the single phase, namely, BaO.6Fe₂O₃. Thus, hard magnet is formed at the sintering temperature of 1280 °C. The values of Br and Hc heavily depend on the purity of raw materials and crystal size, which function to control the shift of the domain wall. This observation suggests that the crystal size is not proportionate to the number of boundaries between crystals and the number of blocks of the domain movement; thus, resistance toward demagnetization center tends to increase, and vice versa [9-10]. Compared with the commercially available ferrite, the BaO.6Fe₂O₃ magnet sample possesses a remanence Br of 2560 Gs, Hc of 941 Oe, and sintering density of 5.3 g/cm³. Apparently, the Br obtained in the BaO.6Fe₂O₃ magnet is smaller than that obtained in the commercially available magnet, and the curve is narrower compared with that of the produced BaO.6Fe₂O₃ magnet. The density value of BaO.6Fe₂O₃ is also extremely lower than that of the commercially available ferrite.
Figure 6: Hysteresis Curve (B-H Curve) of BaO.6Fe2O3 sintered magnet at 1280°C.

5. Conclusion
The production of permanent magnet based on BaO.6Fe2O3 sintered at 1280 °C indicates the formation of hard magnet with a single-phase BaO.6Fe2O3 having a crystal size < 3 μm exhibiting a nonhomogeneous grain distribution and numerous pores. The remanence Br obtained is 2160 Gs and coercivity Hc is 3215 Oe, whereas the Br and Hc values of other products are 2560 Gs and 941 Oe, respectively. The density value of the sintered BaO.6Fe2O3 sintered at 1280 °C is 4.43 g/cm³, whereas that of the commercially available sintered product is 5.3 g/cm³. This result will further investigated on the water instrument manufactured by PT Multi Instrumentasi Bandung. If the results show improvement, this product will be recommended to the members of the magnet consortium.

6. Acknowledgement
We would like to extend our gratitude to Magnet Consortium for their continuous effort in the development of magnetic materials for water meter sensors, which inspired the work presented in this paper. We also wish to thank Prof. Perdamean Sebayang (Lembaga Ilmu Pengetahuan Indonesia) for his valuable contribution in the completion of this paper.

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