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HIGH MAGNETIC INDUCTION PERMANENT MAGNETS[1]

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New permanent magnets developed in SVÚM have a convergent anisotropic crystal orientation which concentrates the magnetic flux into a smaller cross-section than that of the magnet. Magnets of this type produce substantially higher peak values of the air-gap flux density than conventional homogeneously anisotropic magnets. In the present paper, the effect of convergent orientation on the external flux density is explained by means of a theoretical model. Experimental data obtained on $SmCo_5$ convergently oriented magnets are in agreement with the calculated values.

ВЫСОКАЯ МАГНИТНАЯ ИНДУКЦИЯ ПОСТОЯННЫХ МАГНИТОВ

В Государственном НИИ материалов в Праге разработаны образцы новых постоянных магнитов с конвергентной анизотропной ориентацией кристаллов, которая сосредоточивает магнитный поток в площадь сечения, меньшую, чем сечение магнита. Магниты этого типа позволяют существенно повысить максимальную величину магнитной индукции в рабочем зазоре магнита по сравнению с существующими однородно анизотропными магнитами. Влияние конвергентной ориентации кристаллов на магнитную индукцию вне магнита объяснено на основе теоретической модели. Экспериментальные данные, полученные на основе измерений на образцах конвергентно-ориентированных магнитов $SmCo_5$, хорошо согласуются с расчетными величинами.

I. INTRODUCTION

In many applications the main purpose of a permanent magnet is to supply the highest possible magnetic flux to an air gap or in a pole piece. With a view to enhance flux density we worked on magnets having an anisotropic magnetic structure wherein the orientation of the axes of easy magnetization is convergent (Fig. 1a). The convergent structure can have a linear, curvilinear, continuous or discrete, two or three-dimensional configuration. Several research reports, papers and patents resulting from such studies and dealing with magnet structures, processing and application have been published. Magnets of this type enable us to substantially increase the value of flux density in the vicinity of the pole in comparison with conventional homogeneously oriented magnets. The raising of the flux density supplied to the exterior is attained in a smaller cross-section than the cross-section of the magnet where the convergent orientation concentrates the magnetic flux.

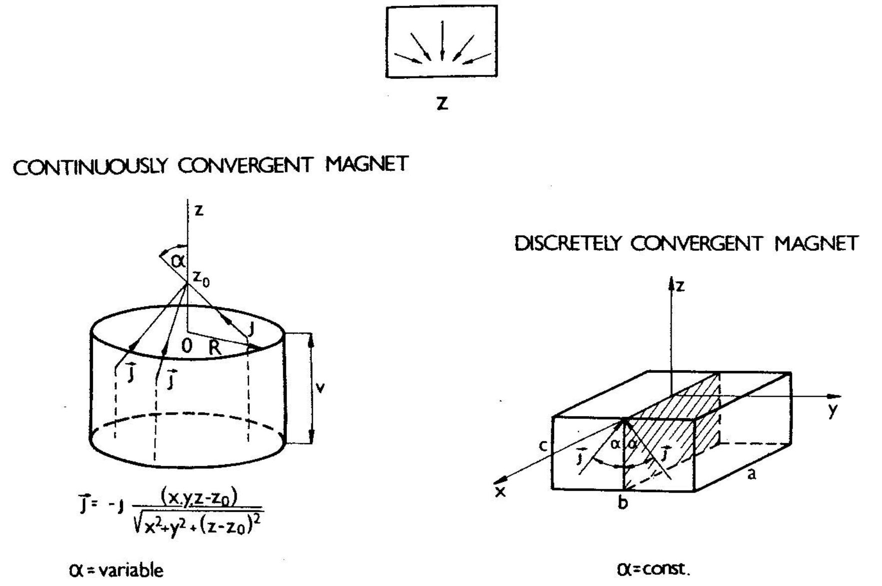

Fig. 1. Schematic view of magnets with a varying structure of the polarization vector ***J***.

II. THEORETICAL MODEL

The effect of convergent magnetic orientation on the external flux density was studied by means of a theoretical model. For calculations of the flux density produced by continuously convergent magnets the polarization vector ***J*** was determined by a vector function of place which is constant in magnitude and varies only in direction. The flux density was calculated from the magnetic scalar potential [1]. It should be noticed that the term containing $\Delta . \boldsymbol{J}$ is not zero here and a nonuniform magnetic charge density occurs on the specimen surface. The flux density components were found by differentiating under the integral in the equation for the scalar potential and then by numerical integration of the result.

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A special linear form of $\boldsymbol{J}(\boldsymbol{r})$ in Fig. 1b [2] shows $\boldsymbol{J}$ being directed to the focus z_0 on the z-axis outside a cylindrical magnet. It can be seen in Fig. 2 that such a magnet having the dimension ratio $v/R = 1$ supplies considerably the higher flux density component B_z into a restricted region near the surface of the magnet in comparison with a homogeneously oriented sample of the same dimensions. The nearer z_0 to the magnet surface the higher is the B_z value obtained in the proximity of the surface. A simple expression has been found for the flux density produced by this magnet at the point z_0:

$$B_z(0, 0, p) = \frac{J}{4} \ln \frac{(p+1)^2(p^2+1)}{p^2[(p+1)^2+1]} \qquad \text{where } p = z_0/R.$$

It should be noted that the maximum flux occurs just on the surface of the magnet, not in the focus.

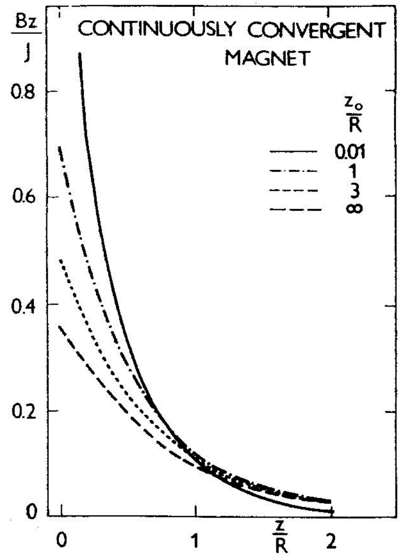

Fig. 2. Calculated flux density component B_z of a homogeneously ($z_0/R \to \infty$) and convergently oriented cylindrical magnet as a function of the distance from the pole surface.

In case of discretely convergent magnets the assumption $\boldsymbol{J} = \text{const.}$ was used for calculation. The flux density was found by linear superposition of terms arising from each particular segment of the convergent magnet. These simplifying assumptions are often made when calculating the flux density produced by permanent magnets with a high coercive force and a high value of the relation K/J_s^2. High uniaxial anisotropy depresses the fluctuation of the polarization vector $\boldsymbol{J}$ caused by nonuniform demagnetization fields. The square-shaped demagnetization curve $J(H)$ with H_k exceeding the value of the demagnetization field which acts in the magnet is required too, so that serious demagnetization effects may not occur. Thus surfaces with a uniform magnetic charge density are supposed to be the only sources of the magnetic field. McCaig [3] gives formulas for the calculation of the magnetic field produced by rectangular planes with a uniform magnetic charge density. Craik [4] mentioned calculation methods appropriate for uniformly magnetized cylinders. In this way we calculated the flux density produced by discrete convergent magnets prepared by assembling homogeneously oriented segments.

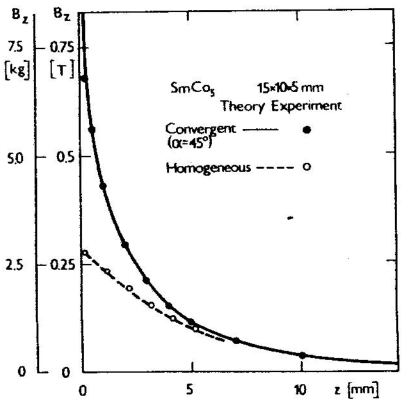

Fig. 3. Example of a discretely convergent SmCo$_5$ magnet.

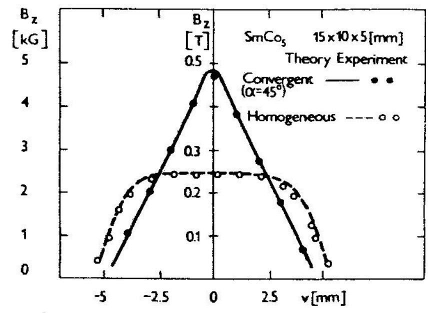

Fig. 4. Example of a discretely convergent SmCo$_5$ magnet. Calculated curves and experimentally obtained data of the flux density component B_z versus the y-coordinate at a distance $z = 0.8$ mm.

III. EXPERIMENTS AND RESULTS

Various types of convergent magnets were prepared from existing hard magnetic materials for theoretical study and practical applications. These magnets have a two- or three-dimensional convergent orientation. In order to compare theoretically calculated values with experimental data we manufactured a well defined and simple SmCo$_5$ magnet with two linearly converging directions as shown in Fig. 1c. A similar approach is reported to be used in the construction of multipole magnet systems for focusing and guiding charged particle beams [5]. In Fig. 3 we present the dependence of the flux density component B_z on the distance from the magnet surface which shows an extremely high flux density and its gradient in the vicinity of the surface. This is a typical feature of strongly convergent magnets as well as a narrow peak on the dependence of B_z on the y-coordinate (Fig. 4). The highest value of $B_z = 0.68$ T measured at the distance 0.25 mm from the surface of this magnet approximately doubles the value obtained on a homogeneously oriented sample of the same material and size.

IV. CONCLUSIONS

With convergently oriented magnets higher gap densities not attained with common permanent magnets, are possible [6]. The use of these advantages promises an improvement in efficiency, output and miniaturization of certain permanent magnet systems and the development of entirely new devices not possible with conventional anisotropic magnets.

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