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MAGNETIC PROPERTIES OF COBALT-RARE EARTH MAGNETS FOR MICROWAVE APPLICATIONS

by

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SUMMARY A family of sintered cobalt-rare earth alloys utilizing Sm, Pr, La, or Ce misch metal has been developed. Each alloy is designed to optimize one of the following characteristics:

I. Magnets which exhibit magnetic energy products in excess of 20 million gauss oersteds.

II. Magnets which exhibit reversible demagnetization behavior in adverse fields up to 14,000 oersteds.

III. Magnets using inexpensive rare earth metals to maximize the magnetic energy per unit cost.

These alloys should extend the range of use of cobalt-rare earth magnets for microwave devices.

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KEY WORDS permanent magnets, rare earth permanent magnets, cobalt-samarium permanent magnets, traveling wave tube magnet, microwave tube magnets, magnetic measurement

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MAGNETIC PROPERTIES OF COBALT-RARE EARTH MAGNETS FOR MICROWAVE APPLICATIONS

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ABSTRACT

A family of sintered cobalt-rare earth alloys utilizing Sm, Pr, La, or Ce misch metal has been developed. Each alloy is designed to optimize one of the following characteristics:

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These alloys should extend the range of use of cobalt-rare earth magnets for microwave devices.

Cobalt-rare earth alloys show promise for use in microwave devices since they exhibit high induction values coupled with high resistance to demagnetization.

Because of early success, cobalt-samarium has received the most attention relative to the preparation of high energy magnets.[1,2] Initial magnets were made by simply pressing fine Co-Sm alloy powder. These magnets oxidized at slightly elevated temperatures and were magnetically unstable. Densification to nearly full density by sintering[3,4,5] or by hydrostatic uniaxial compression[6] appears to have eliminated this problem.

Success in the preparation of high energy, stable Co-Sm magnets by a liquid phase sintering process[5] has prompted us to explore ternary alloy systems in which samarium has been replaced by praseodymium, lanthanum, cerium, and misch metal (MM). Our studies have shown the value of the liquid phase sintering process for making these ternary alloys. In most instances 75% to 85% of the maximum energy product limit has been achieved.* Interesting differences from the binary Co-Sm alloy properties are observed when Pr, La, Ce, and MM are substituted for samarium to form ternary alloys. A detailed discussion of the preparation and properties of these ternary alloys has been given in a recent paper.[7]

Co-Sm Alloys

Cobalt-samarium alloys have received the most attention so far, and accordingly will be the first materials used in microwave devices. A number of studies are currently underway to prepare cobalt-samarium magnets, in quantity, for application to traveling wave tubes.[8,9]

By varying the composition and processing, it is possible to vary the B:H characteristics of these alloys. This is shown in Fig. 1 and indicates that the usual trend is for the coercive force to drop as changes are introduced to increase the B_r and energy product $(BH)_{max}$.

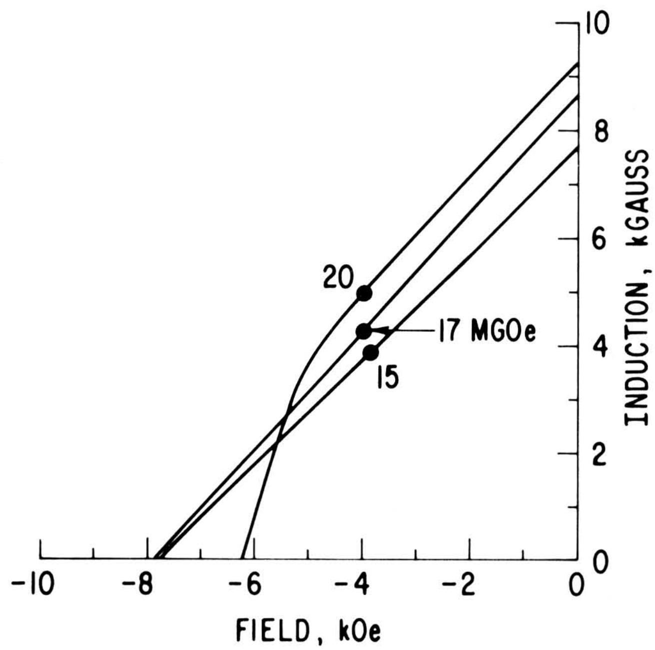

Fig. 1 B:H curves for cobalt-samarium alloys. The different curves represent different compositions and processing. (Samples A, B, and C listed in Table I).

The B:H properties are also influenced by the peak magnetizing field. The high intrinsic coercive force of these alloys requires that high fields be used for magnetizing. This is reflected in the results in Fig. 2 where the B:H curves for increasing magnetizing fields are shown. The coercive force H_c shows the most marked increase with peak field. This is important for TWT magnets where the load line slope is less than -1. To attain the high fields required for saturation we have used a niobium-tin superconducting magnet which can operate to 100 KG. A pulsed field of high field strength might also be used.

*The maximum value of $(BH)_{max}$ is limited by the saturation, B_s, of the alloy. This limiting value is $B_s^2/4$.

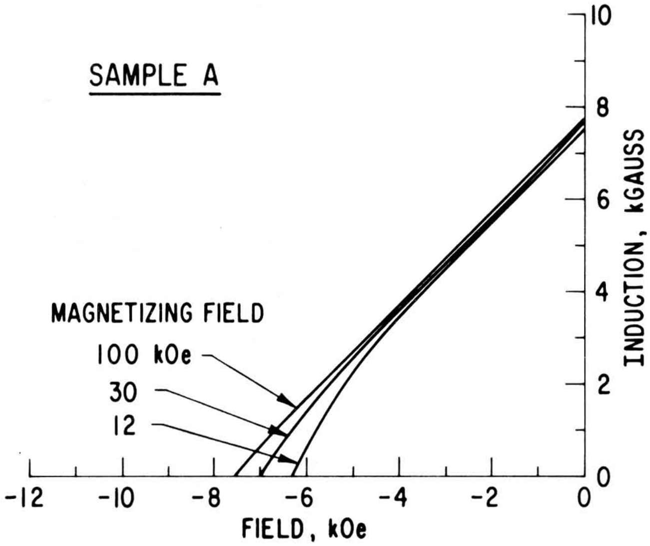

Fig. 2 B:H curves for a cobalt-samarium sample magnetized at different fields. (Sample A listed in Table 1).

The cobalt-rare earth magnets are made by a powder metallurgy process which has an inherent advantage of yielding uniform properties. We have observed a high degree of uniformity of magnetization for a batch of 88 Co-Sm TWT half ring magnets. A histogram showing this uniformity is given in Fig. 3. In this case, 99% of the magnet magnetizations were within ± 4% of the mean.

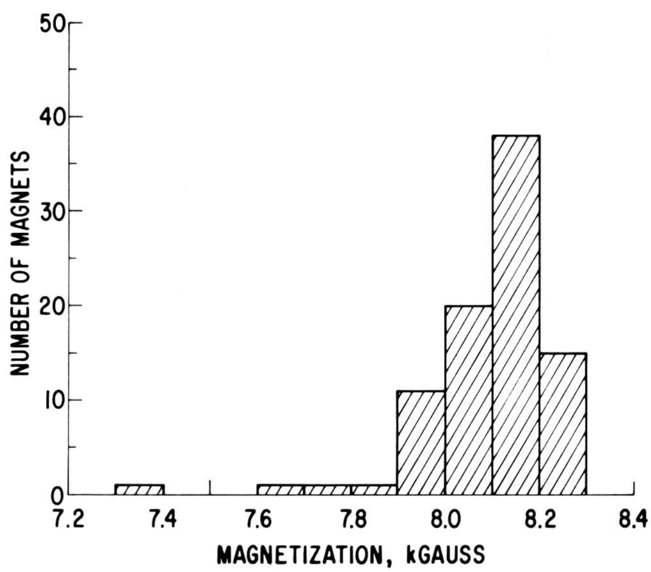

Fig. 3 Histogram showing variation of magnetization for 88 traveling wave tube magnets. The mean is 8.10 kGauss. The standard deviation is 0.138 kGauss.

Co-Pr-Sm Alloys

Praseodymium, in certain alloys, increases the saturation, and correspondingly results in alloys with higher energy product values (Fig. 4). Some of these alloys also possess high coercive force values (Table 1) and thus they are potential candidates for microwave applications. The parameter H_d listed in Table 1 is the value of field at which a B/H load line slope of -1/2 intersects the demagnetization curve. We have found this a useful property value to characterize magnet alloys for a number of TWT applications. Note that the Co-Pr-Sm alloys have the highest H_d values shown in Table 1.

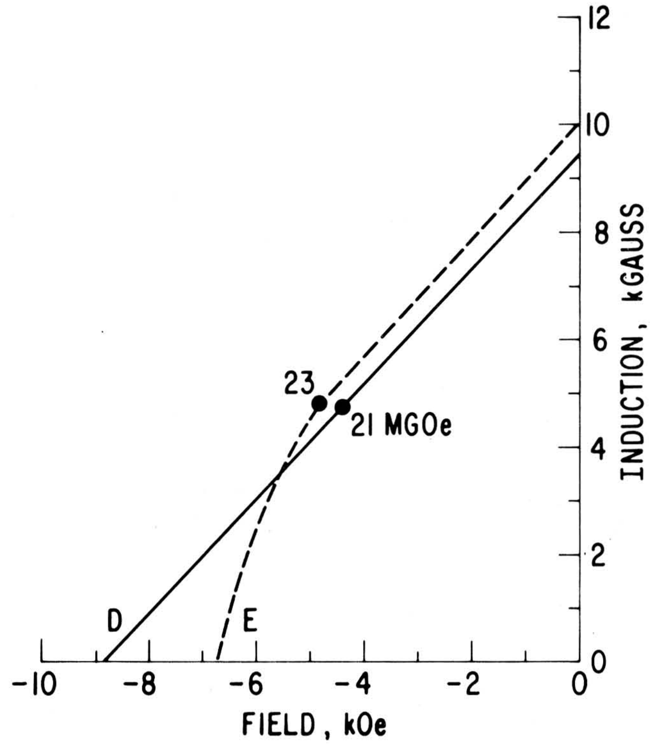

Fig. 4 B:H curves for cobalt-praseodymium-samarium alloys. (Samples D and E listed in Table 1).

Co-La-Sm Alloys

The lanthanum alloys have an extremely square magnetization curve. In one alloy the magnetization remains positive to 28,000 Oe. (Fig. 5) This results in a B curve that is linear into the 3rd quadrant beyond 10,000 Oe. The recoil permeability is very low and the useful recoil energy approaches the $(BH)_{max}$ value.

Co-MM-Sm Alloys

The replacement of samarium by cerium misch metal (MM) is highly desirable on the basis of raw material cost. Samarium is many times more expensive than misch metal. The B:H characteristics of the Co-MM-Sm alloy in Fig. 6 are noteworthy because 42% of the samarium has been replaced by misch metal. This has been achieved without any appreciable loss of magnetic properties.

Stability of Magnets

One of the early disappointments with Co-Sm

TABLE 1

Summary of Magnetic Properties for Cabalt-Rare Earth Magnets

Sample	Alloy	Magnetizing Field kOe	B_r kG	H_c kOe	$_JH_c$ kOe	(BH)m MGOe	Packing %	H_d at B/H = -1/2 kOe
A	Co-Sm	12	7.5	-6.4		13.4	85	-4.70
A	Co-Sm	30	7.6	-7.0		14.7	85	-5.05
A	Co-Sm	60	7.7	-7.2		14.8	85	-5.10
A	Co-Sm	100	7.8	-7.5		15.0	85	-5.20
B	Co-Sm	100	9.3	-6.2	- 9.2	20.3	95	-5.40
C	Co-Sm	100	8.8	-8.0	-23	17.6	91	-5.50
D	Co-Pr-Sm	100	9.5	-8.9	-17.8	21.1	95	-6.15
E	Co-Pr-Sm	100	10	-6.8	- 7.8	23.0	96	-5.80
F	Co-La-Sm	100	7.3	-7.1	-28	12.9	94	-4.80
G	Co-MM-Sm*	60	7.9	-7.2	-17	15.5	95	-5.10

*Misch metal is a commercial rare earth alloy of Ce, La, Nd, Pr, and Gd.

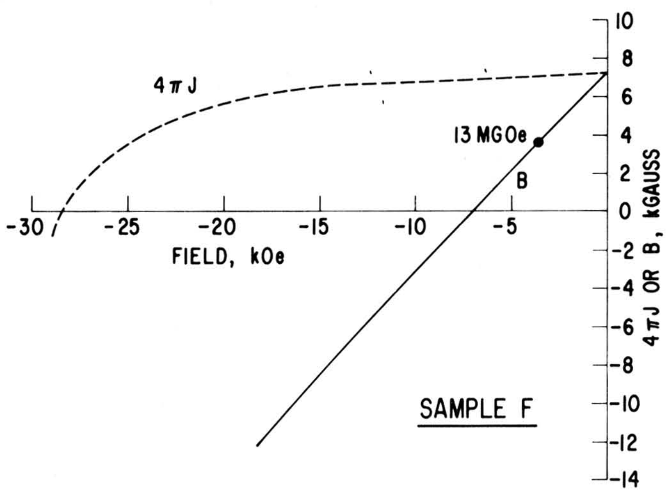

Fig. 5 Magnetization and B:H curve for a cobalt-lanthanum-samarium alloy. (Sample F listed in Table 1).

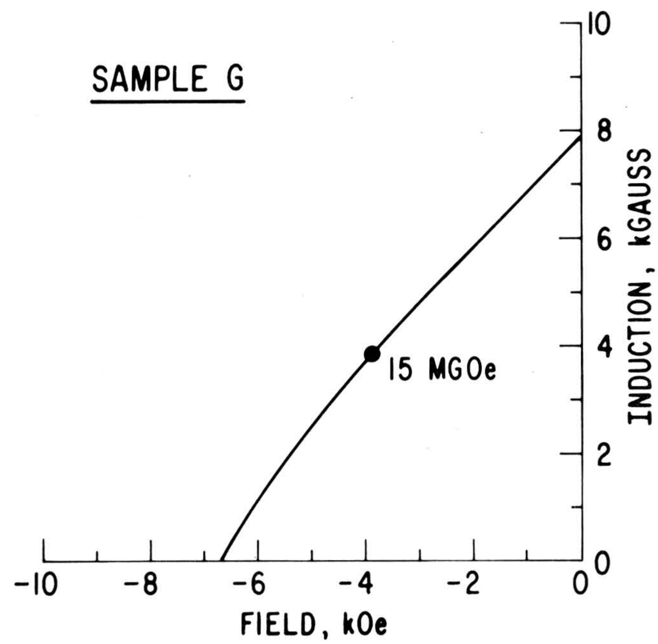

Fig. 6 B:H curve for a cobalt-misch metal-samarium alloy. (Sample G listed in Table 1).

magnets was their instability due to an oxidation process when heated in air to moderate temperatures (e.g. 100°C).[1] Sintering the magnets to a closed pore structure eliminates the loss of magnetic properties during long time exposure to air. Samples of Co-Sm have been heated at 150°C in air for over 1100 hours without permanent loss of magnetic properties. A sintered sample of Co-Pr-Sm likewise did not show any permanent loss in B:H characteristics after 970 hrs. at 150°C in air.

There is another kind of property loss which these magnets suffer, as do most magnets. This is a loss in magnetization during heating wherein the loss increases with temperature until the magnetization reduces to zero at and above the Curie temperature. This loss is recoverable if the sample is remagnetized; however in a device this remagnetization may not be possible and changes due to temperature excusions must be considered in the device design. Irreversible temperature loss has been measured for some of the

TABLE 2

Magnetization and Irreversible Loss Percentages at Room Temperature After Exposure to Higher Temperatures[a]

	Co-Sm[b]	Co-Pr-Sm	Co-La-Sm
Initial Magnetization, kGauss	7.95	8.35	6.37
Magnetization after 150°C, kGauss	7.67	7.74	5.86
Irreversible Loss, %	4	7	8
Magnetization after 200°C, kGauss	7.36	7.48	5.54
Irreversible Loss, %	7	10	13
Magnetization after 250°C, kGauss	6.41	6.67	5.03
Irreversible Loss, %	19	20	21

Note(a) Sample L/D = .206. Measurements made with a torque magnetometer. Magnetometric demagnetizing factor = 0.32 and B/H = -0.47.

Note(b) The reversible temperature coefficient over this range is -0.04% per °C.

alloys reported in this study and the results are given in Table 2. While the losses in Table 2 are greater than are usually observed for Alnico they are less than those reported for hard ferrites.[10] The comparison with Alnico is somewhat misleading in that the Table 2 results were measured on samples with a small length to diameter ratio (L/D) of 0.2. It is very likely that Alnico would also suffer a comparable loss for such a small L/D ratio. Irreversible losses for all magnet materials are influenced by the operating point on the B:H curve. Long samples tend to suffer lower irreversible losses than short samples. For example, in one instance a Co-Sm magnet with an L/D of 4 suffered a loss of only 7% when heated to 450°C in air. This is shown in Fig. 7. The results in Table 2 must be regarded as tentative and, since the samples were selected, the results are perhaps the best to be expected. We have found much greater losses in other samples and conclude that the irreversible losses are very sensitive to processing. Additional study is needed to clarify which of the numerous processing factors affect irreversible loss behavior.

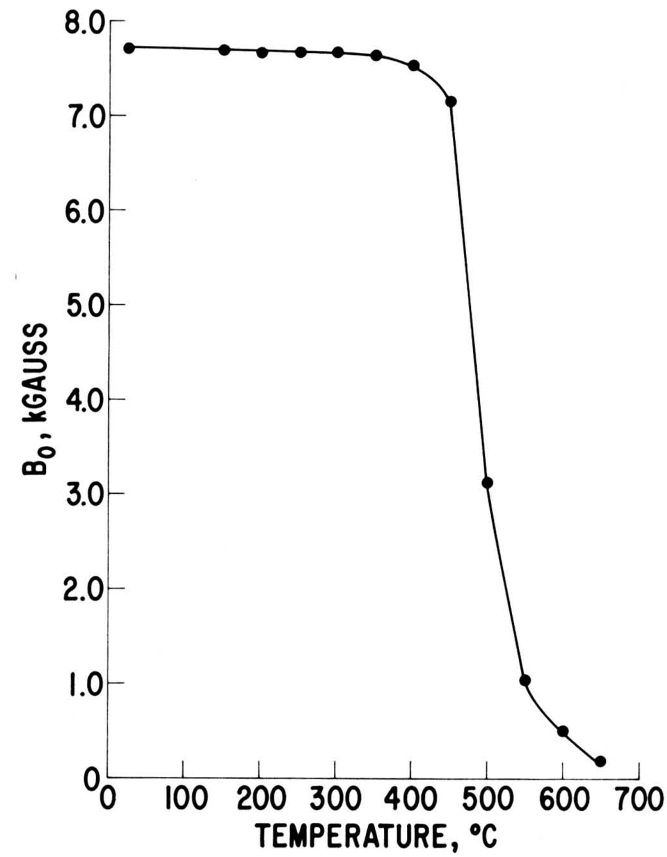

Fig. 7 Open circuit magnetization of a long sample (L/D = 4) at room temperature after exposure to the elevated temperature plotted. This irreversible loss is recoverable by remagnetization of the sample.

Measurement methods used to gather the data presented in this report are described in a previous paper.[11]

SUMMARY AND CONCLUSIONS

1) Liquid phase sintering is effective for the preparation of high quality Co-Sm, Co-Pr-Sm, Co-La-Sm, and Co-MM-Sm alloys.

2) Sintering to a high density, i.e. over 90% of full density, eliminates the permanent, non-recoverable loss of magnetic properties during long time exposure to air at temperatures of 150°C.

3) Magnets with energy product values of 20 MGOe and over have been achieved for alloys in the Co-Sm and Co-Pr-Sm systems.

4) The sintered Co-La-Sm ternary alloys have a very high degree of resistance to demagnetization. The recoil properties are excellent.

5) The results achieved by replacement of samarium by misch metal are noteworthy because the magnetic values are high and the cost of misch metal is much lower than samarium.

In conclusion, it is clear that a new family of permanent magnet alloys is evolving which will cover a wide span of properties. Some of these properties have never been previously attained. Use of these new permanent magnet alloys to their best advantage will require considerable creative design on the part of the microwave device engineer.

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