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ELF Magnetic Fields in Electro-Steel and Welding Industries.

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ABSTRACT

In the welding and steel industries strong electric currents are used for a variety of heating purposes. Since these currents set up related magnetic fields it is of interest from a medical point of view to study the properties of these fields.

All the measurements were performed in the working positions at the machines. Field flux densities in the range 0-10 mT at mostly 50 Hz were found in both types of industries. Near induction heaters the magnetic flux densities were up to 60 mT and with the frequency range 0-10 kHz.

Knowledge of industrial field characteristics such as frequency, flux density, and distribution will facilitate laboratory research aimed at determining possible biological effects of magnetic fields. These results indicate that biological effects of the magnetic fields probably occur (magnetophosphenes) although these phenomena are difficult to recognize in industrial localities with high background illumination.

KEY WORDS

ELECTROMAGNETIC FIELDS, BIOLOGICAL EFFECTS, OCCUPATIONAL MEDICINE.

INTRODUCTION

The biological effects of electromagnetic fields have interested researchers in many scientific disciplines ever since the middle of the nineteenth century. A few reviews of the considerable literature on the subject have been published [Barnothy, 1964; Barnothy, 1969; Battocletti, 1976; Royal Swedish Academy of Engineering Sciences, 1976; Llaurado et al., 1974; Presman, 1970].

Most of the investigations that have been described have been carried out under laboratory conditions, and static (DC-), pulsating, and alternating (AC-) fields have been used. Much of the work has been done on man or experimental animals.

The pattern and goal of the investigation has varied greatly from one researcher to another, and most of the considerable heterogeneous literature is difficult to use in the assessment of possible risks to workers in industry.

In order to increase knowledge on how electromagnetic fields affect man, intensified research, both epidemiological and of more fundamental biological nature, is required. An essential requirement for both types of investigation is increased knowledge on low-frequency (LF) magnetic sources of radiation, as have been pointed out elsewhere [Royal Swedish Academy of Engineering Sciences, 1976].

The object of this work is therefore to elucidate sources of LF magnetic fields present in industrial environments, in order to obtain a realistic basis for further laboratory investigations. Such data are required to establish objective, practical threshold values.

THE WELDING AND STEEL PRODUCTION TECHNIQUES EXAMINED

Electric current is used in both welding and steel production for heating materials. By allowing the current to pass through the material this is heated to a suitable temperature. Since welding techniques and methods of steel production are rarely known by scientists investigating the effect of electromagnetic fields on man, a brief account therefore follows of the methods for which estimation of the magnetic flux density has been carried out.

Electric welding apparatus

Common methods of electric welding include,

Arc welding

Resistance welding

Electroslag refining

The term arc welding covers a large number of welding techniques in which the heat energy required is generated with the aid of an electric arc. With a few exceptions the arc is established between a metal electrode and the part to be welded. Here the term arc welders means large mechanical apparatus. The most common welding method for small objects is manual metal arc welding (MMA welding), in which currents of up to 600 A, AC or DC are used.

In submerged melt welding an electric arc is established between a continuous, bare electrode and the work piece. Several electrodes (and arcs) may be used simultaneously. The electrode is propelled by means of an automatic device. The seam is coated with a powder that totally envelops the arc and melt, which are thus not visible during the procedure. Some of the powder is used up during welding, and forms a slag film over the weld. This type of welding is done with relatively large currents (up to c. 1,100 A).

A special form of resistance welding is called flash welding, and is used for joining bars, profiled rods and sheet iron. The parts are clamped in the machine with a gap between the abutting surfaces. One part is fixed in an immobile jaw and the other in a jaw that travels in a carriage guide. The ends of the parts are brought together slowly. When they touch they will "flash" that is, minute particles of molten metal will fly off. This flashing is continued until the entire faces of the abutting ends have reached a welding heat, when heavy pressure is applied, forcing the ends together and completing the weld. Currents of up to 100 kA are used, depending on the dimensions of the material, the nature of the construction, the physical properties of the material, etc. Alternating current is almost invariably used.

Spot and seam welding are based on the same principle as flash welding, and are carried out without additives.

Electroslag refining (ESR) is a type of automatic ingot welding in which the melt is formed in the ingot mould that is made up of (i) the edges of the part to be welded and (ii) of water-cooled coppar jaws that are in close apposition to the job. ESR is a Russian invention, originally designed for welding very large objects. Direct current is commonly used, but alternating current may occur.

Electric steel furnaces

As a rule low frequency electric current is used in the electric steel industry for smelting, hardening and heat treatment. In many of the methods the currents used are very high. Brief descriptions follow of a few common methods that constitute potential sources of radiation. The most common types of electric steel furnaces are, Arc furnace

Ladle furnace

Induction furnace

Channel furnace

In arc furnaces the heat is generated by arcs that are established between an electrode and the molten metal. Arc furnaces are used as smelting machines for merchant iron or for the production of alloy steel. In the latter case the induction stirrer is used to reduce the refining time.

Ladle furnaces are used for refining. High-class steel is obtained with a combination of inductive stirring, arc heating, and vacuum degassing. A ladle furnace installation can be made up of the following main elements,

I) Heating component, in principle similar to an arc furnace, in which the furnace is replaced by a ladle of austenite material.

II) A cylindrical inductive stirrer which is fed by a rotary or static converter.

III) Vacuum equipment with vapour diffusion pump and vacuumsealed cover.

In an induction furnace the heat is produced by alternating current, and in turn this causes eddy currents in the melt. Two types of induction furnace exist, driven by mains (50 Hz) and by high frequency, respectively. Mains supply furnaces for smelting, superheating and heat mainteneance are used in the manufacture of cast products, chiefly cast iron. High frequency induction furnaces are used for steel alloys, carbon steel and other metals. The frequency most commonly used is 600 Hz.

The channel furnace is also an induction furnace. Here a coil is surrounded by a channel with a closed circuit of molten metal. The closed circuit forms a short-circuited secondary winding in a highly unconventional transformer. Energy is transmitted from the current source to the melt in the form of "short-circuiting losses". Channel furnaces run on mains supply are used for smelting, superheating and heat maintenance.

Induction heaters have a variety of uses, such as heating, hardening, heat treatment and soldering. Frequencies of up to 10 000 Hz are used. Induction heaters are usually built for specific purposes. The principle is that the heat in the material is obtained from induced currents.

MEASURING TECHNIQUE

In collaboration with industrial companies and institutes we have selected a number of welding and steel processes for which the magnetic fields have been mapped out. We have been particularly careful to carry out the measurements under conditions comparable to working conditions.

The magnetic fields in the various industrial processes were measured with the aid of a gaussmeter (F W Bell, mod 610Z, Colombus, Ohio, USA) equipped with a Hall type detector. With this apparatus it is possible to measure the field in three dimensions, though not simultaneously, which is unimportant in this connexion. The probe was fixed in a stand to eliminate movement during measurements.

To the gaussmeter, which operates within 0-10 kHz and the dynamic region 0.1 mT - 10 T*, were coupled an instrument tape recorder (Tandberg 100, Oslo, Norway) and an UV-recorder (type SE 2005/SE Laboratories Ltd, Feltham, England).

* 1 tesla (T) = 1 Wb/m^2 = 10^4 gauss (G)

From the signals for x-, y- and z-directions it is possible to calculate the resultant for magnetic flux density, using the formula,

$$|B| = \sqrt{B_x^2 + B_y^2 + B_z^2}$$

Measuring points were selected in order to obtain the closest possible impressions of the magnetic fields to which workers are exposed. The flux densities recorded are therefore not necessarily the maximum values for any given method, but are to be regarded as representative of the type of welding or smelting procedure within the area round the machine on which the operator works.

RESULTS

Figs 1 and 2 and tables I and II show the flux densities and the intervals within which they normally vary (in time and space) at the site ordinarily occupied by the operator. The intervals are related to the periods of time when the different processes are used under normal circumstances. The results are usually based on measurements near more than one piece of welding apparatus or electric furnace. The reason for the scattering of the results is the variation in distance to the machines and also the variation in the currents used.

Fig 1 A refers to the earth's magnetic field, in which the maximum and minimum limits show the geographical variation in the resultant of the field. Fig 1 B was recorded in MMA welding, in which the relatively high values are due to the proximity of the work area to the live cables.

Other welding processes (for methods, measuring distances, etc., see table I), generate magnetic flux densities within the range $10^{-4} - 10^{-2}$ T.

The maximum values are thus several hundred times greater than the earth's magnetic field. Considerable variations may occur owing to the current strength used, proximity to metal bodies, etc. The values given may nevertheless be regarded as characteristic for the respective methods.

Fig 2 shows magnetic flux densities recorded in other industrial electric steel processes. Fig 2 A shows the range of variation in the earth's magnetic field. The ladle furnace (D) gives a relatively high flux density in the proximal zone. Particularly high values are recorded round induction heaters (I). With these both magnetic flux density and frequency may be high, implying high energy density of the field compared to other electrical processes in the frequency range treated in this work.

DISCUSSION

The purpose of this investigation was to establish the range (time and space) within which the magnetic flux density could conceivably vary in different energy-consuming electrical processes in the welding and steel industries. With this knowledge it should be possible to simulate corresponding fields under laboratory conditions and also to predict and describe possible physiological effects.

Our industrial measurements comprise only the magnetic component of the field. This is because the processes studied require high or extremely high currents, even though a very low voltage is used. The electric strength is therefore as a rule small in the electromagnetic fields measured. According to the literature, fields of this order of size give no biological effects [Kornberg, 1976], and the fields produced by the processes described may probably therefore be disregarded.

Induction heaters may constitute an exception to this principle, however. Owing to the high magnetic flux densities recorded round them we plan to carry out a special study of induction heaters in which the electric fields will also be measured.

It is not yet possible to compare the values for magnetic fields with existing threshold limits in order to assess possible effects on man during industrial processes. This is mainly because existing threshold values lack scientific basis. The influence of low frequency magnetic fields on living tissue has so far been studied mainly on very complex biological systems concerning experimental animals and/or human volunteers. Very often the method of investigation has had an epidemiological approach. It seems that this way of exploring Extreme Low Frequency (ELF) fields effects could make it difficult to detect the specific effect of the field, since these effects are of the same order of magnitude as other systemic responses with different genesis. The magnetobiological responses may be buried in "the physiological noise".

Consequently it is important to simulate the flux density data measured in industry in the laboratory to study field effects on very well defined physiological systems in order to enable an evaluation of the specific influence of the Extreme Low Frequency (ELF) fields on such systems.

This type of approach can undoubtedly yield better information on how time-variable magnetic fields affect biological systems. Certain of the flux densities measured in this investigation cause magnetophosphenes through their effect on the retina [Lövsund et al., 1978]. The phosphenes are experienced as light phenomena the properties of which depend on the frequency and flux density of the magnetic field and on the properties of the background lighting.

This phenomenon, which has been known for about 100 years, is clear evidence that fields of the type occuring in many industries do indeed have biological effects. In order to improve knowledge on how low frequency magnetic fields affect man in industrial environments increased understanding of how the magnetic field influences biological structures at cellular level is needed. It will then be possible to predict effects at higher levels, and to establish more reliable threshold values.

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Table 1. Electric welding apparatus

	Source of radiation	Current (kA)	Frequency (Hz)	Distance from source (m)	Numbers of the measured eqipment	Notes
A	Earth magnetic field	–	–	–		
B	MMA-welder	0.24–0.43	0 o 50	0–0.8	6	
C	Submerged melt welder	0.65–1.05	0 o 50	0.1–0.5	3	Welding with one or three electrodes parallelly
D	Flash welder	0.13–50	50	0.2–3.0	3	
E	Spot welder	15–106	50	0.2–1.0	2	
F	Seam welder	12	50	0.4–0.5	1	
G	Electroslag refining (ESR)	1.6–1.7	50	0.2–0.9	1	

Table 2. Electric steel furnace

	Source of radiation	Current (kA)	Frequency (Hz)	Distance from source (m)	Numbers of the measured equipment	Notes
A	Earth magnetic field	–	–	–		
B	Arc furnace	3x8–3x40	50	2.0	3	
C	Induction stirrer	2x0.6	10	2.0	1	Used when required in combination with arc furnace
D	Ladle furnace	3x13–3x15	50	0.5–1.0	1	
E	Magnetic stirrer	2x0.8	1.6	1.0	1	Used when required in combination with ladle furnace
F	Induction furnace	3x0.3–3x0.4 0.6–1.2	50 600	0.6–0.9 0.8–2.0	2 5	
G	Channel furnace	2x1.2–2x1.5	50	0.6–3.0	3	
H	ESR-furnace	6	50	1.0–4.0	1	
I	Induction heater	1–4	50–10000	0.1–1.0	5	

REFERENCES

Barnothy, M.F. (ed.) (1964), Biological Effects of Magnetic Fields, vol 1, 327 pp., Plenum Press, New York.

Barnothy, M.F. (ed.) (1969), Biological Effects of Magnetic Fields, vol 2, 314 pp., Plenum Press, New York-London.

Battocletti, J.H. (1976), Electromagnetism, Man and the Environment, 84 pp., Westview Press, Bolder.

Kornberg, H.A., (1976), Biological effects of electric fields in Revue générale de l'électricité, special issue - July 1976, 51-64.

Llaurado, J.G., A. Sances Jr., and J.H. Battocletti (eds.), (1974), Biological and Clinical Effects of Low-Frequency Magnetic and Electric Fields, 345 pp., Charles C. Thomas, Publisher, Springfield.

Lövsund, P., P.Å. Öberg, and S.E.G. Nilsson (1978), Quantitative determination of threshold values of magnetophosphenes. 1977 International Symposium on the Biological Effects of Electromagnetic Waves. Airlie Virginia, U.S.A., in Radio Science, (accepted for publication).

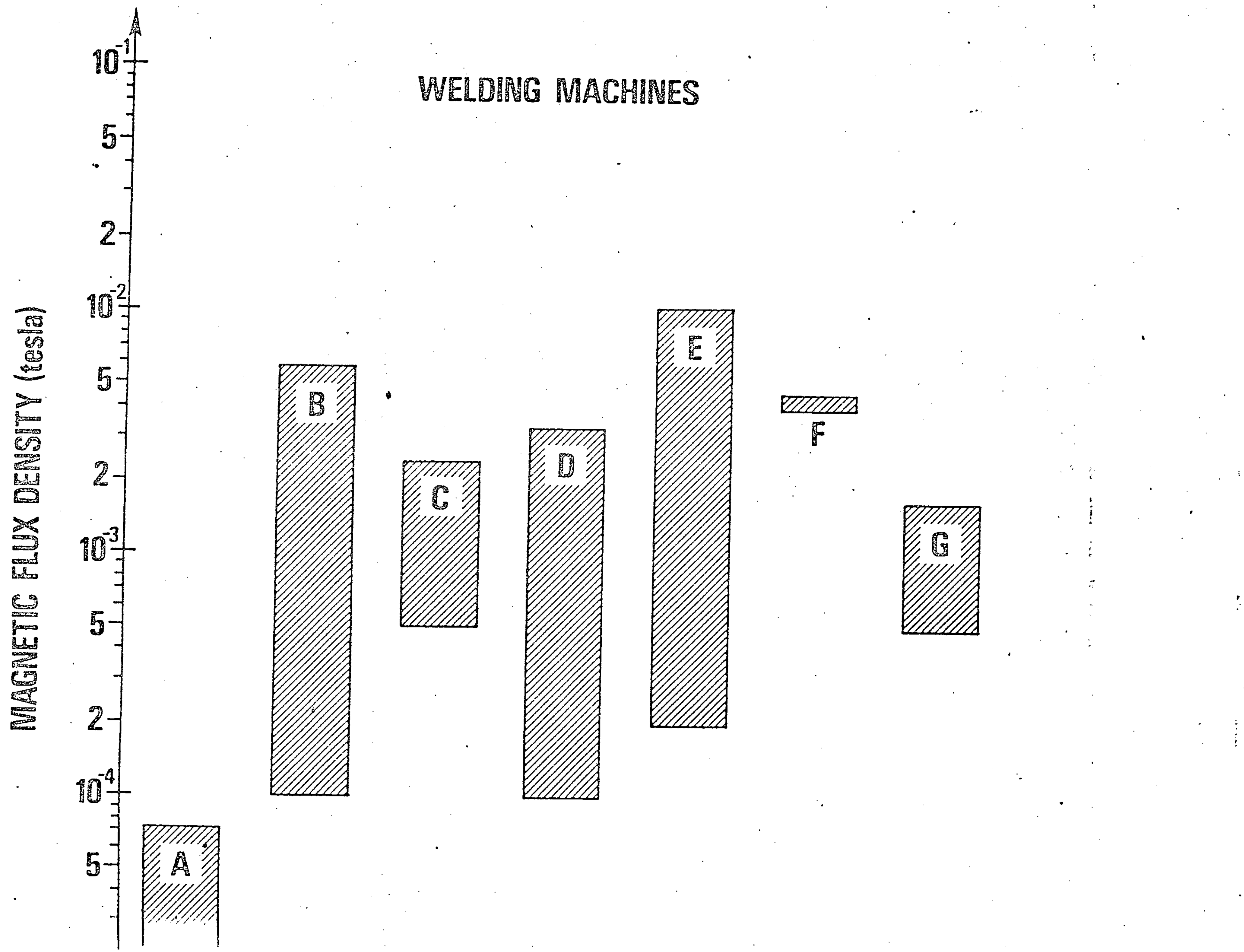
Presman, A.S., (1970), Electromagnetic Fields and Life, 336 pp, Plenum Press, New York-London.

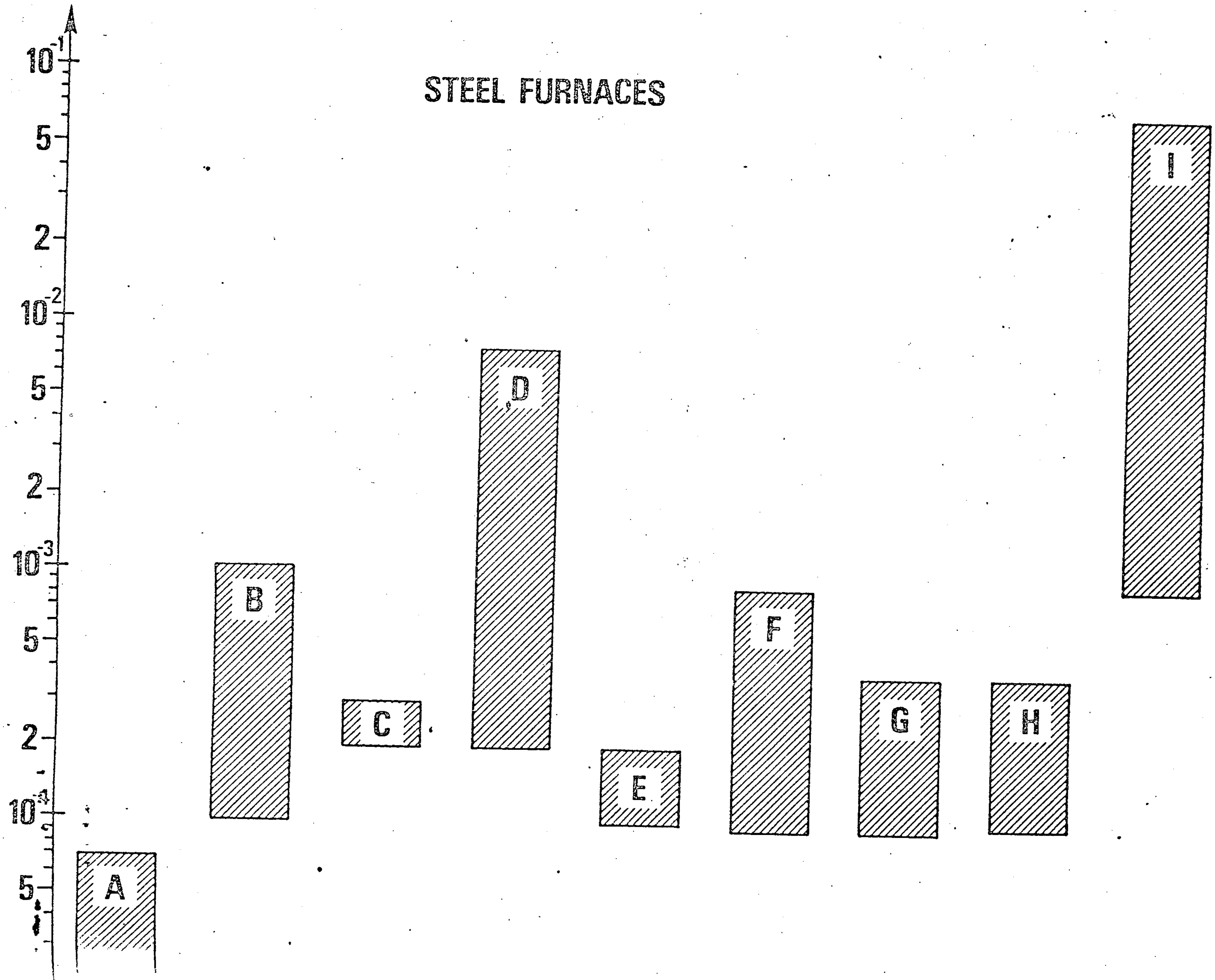
Royal Swedish Academy of Engineering Sciences (1976), Biological Effects of Electromagnetic Fields, 160 pp., IVA-meddelande 210, Stockholm.

LEGENDS

Fig .1: Magnetic flux densities near different welding machines, A = Earth magnetic field, B = MMA-weld, C = Submerged melt welding machine, D = Flash welding machine, E = Spot welding machine, F = Seam welder, G = Electroslagrefining (ESR).

Fig 2: Magnetic flux densities near different steel furnaces, A = Earth magnetic field, B = Arc furnace, C = Induction stirrer, D = Ladle furnace, E = Induction stirrer, F = Induction furnace, G = Channel furnace, H = Electroslagrefining (ESR) furnace, I = Induction heater


WELDING MACHINES
MAGNETIC FLUX DENSITY (tesla)
10^{-1}
5
2
10^{-2}
5
2
10^{-3}
5
2
10^{-4}
5
A
B
C
D
E
F
G


STEEL FURNACES
10-1
5
2
10-2
5
2
10-3
5
2
10-4
5
A
B
C
D
E
F
G
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