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New Data on the Epstein to Single Sheet Tester Relationship

Abstract. *Fifteen years ago, the Epstein frame to the independent Single Sheet Tester (SST92) relation was determined using a large number of correlated grain-oriented samples [1], and the results are reflected in Annex C of IEC standard 60404-3 [2]. Whilst those results were achieved using the same equipment of one reference laboratory, the new data originate from measurements on sample pairs from different manufactures using their own measuring equipment. The resulting Epstein to SST92 ratios show slightly higher values than the old ones, and a considerable dispersion. The reasons for these phenomena are discussed and further experiments for their clarification proposed.*

Streszczenie. *Piętnaście lat temu zaprezentowano porównanie wyników badań różnych próbek blach elektrotechnicznych wykonanych metoda Epsteina i przy wykorzystaniu testera próbek arkuszowych SST92. Wyniki pochodziły z badania próbek w tym samym laboratorium. Nowe wyniki zaprezentowane w pracy przedstawiają badania różnych próbek w różnych laboratoriach. Otrzymano nieco większy rozrzut zmierzonych wartości. W artykule analizuje się przyczyny tych różnic. (**Nowe badania relacji między wynikami pomiarów metodą Epsteina a metodą testera próbek arkuszowych SST**)*

Keywords: Electrical sheet steel, measurement of properties,, Epstein to Single Sheet Tester method relation
Słowa kluczowe: blachy elektrotechniczne, rama Epsteina, tester próbek arkuszowych SST

1. Introduction

Since about 60 years, the Epstein method [3] has been the only reference method worldwide for the determination of the magnetic properties of electrical sheet steel. As far as the application to grain-oriented steels is concerned, the Epstein method is considered more and more reserved. There are three reasons for this: The systematic error (see also [4]), the tedious sample preparation (cutting and annealing) and the restricted applicability with domain refined materials. On the other hand, the increasing acceptance of the independent Single Sheet Tester [2], SST92, is due to simpler sample preparation and extended applicability. Whilst the statistical dispersion behaviour of both methods, i.e. their reproducibility is comparable [5], their systematic errors show, in particular with grain-oriented materials, different characteristics leading to differences up to about 10 % at a flux density of 1.7 T. There is evidence that a partition up to - 8 % should be ascribed to the Epstein frame and up to roughly + 2 % to the SST92.

Thus, for reasons of convenient and economical accomplishment of test measurements, it was discussed among IEC experts to supplement the columns of Epstein reference values in the specification standard for grain-oriented electrical steel, by adding those values measured by means of the Epstein-independent SST92 as alternative reference values.

As a first step in that direction, the IEC/ISO joint working group responsible for this matter decided to collate data describing the Epstein to SST relationship. Such an exercise had already been carried out at a standard laboratory (PTB) in the late 1990s [1] using 254 related Epstein-SST sample triplets. These data have been merged as an informative annex to the IEC SST (1992) standard [2]. However, those data have been measured in one laboratory using the same electrical part of the set-up for both, Epstein and SST measurements. The intention of the new IEC project was to gain such data under realistic conditions, i.e. considering the Epstein to SST relation found for related sample pairs of the same grade but produced by different manufacturers and measured at their laboratory by means of their own set-ups.

2. Prior findings from one reference laboratory

In 1998, the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig, Germany, has measured the magnetic loss and other quantities of 254 sample triplets (2 sheets and 1 Epstein strip sample each cut side by side from one coil strip) comprising eight conventional grain-oriented grades supplied by nine manufacturers. Summarizing the results, a relative difference, δP_{SE} = $100(P_{SST} – P_{EP}) / P_{EP}$, of about + 3 % at 1.5 T and + 5 % at 1.7 T together with a considerable dispersion of ± 2 % were achieved [5]. IEC has referred to these findings in an informative annex to the SST92 standard [1] (see continuous line in Fig. 1).

3. The new data collated from various companies

Seven manufacturers have taken part to this new exercise and have sent their data measured on related pairs of Epstein and SST samples for comparison. Two of them contributed data measured on non-oriented materials of grades 270-50A, 400-50A, 470-65AP, 600-50A and 700-50A (5 sample pairs each). The results δP_{SE} turned out to be between + 14 % and –9 %, they were inconsistent and partly contrary to results published earlier. However, the number of two contributors is too low for any statistical evaluation (as to the statistical character of these kind of results see [5]). On the other hand, the comparison between SST and Epstein with n.-o. material shall take into account RD and TD of the strips. A specific work would have then to be led separately not to introduce heavy duty on the g.-o- material comparison.

However, in the case of g.-o- material simple sample preparation and wider applicability are decisive for the particular interest in the Epstein-SST relationship.

Correspondingly, six manufacturers have contributed δP_{SE} results measured on 5 or more samples of their g.-o. products, i.e. using the grades M90-23P, M100-27P, M103-27P, M105-30P (2x), M130-27P, M110-23S, M120-23S, M120-27S, M130-27S, M130-30S, M140-30S (2x), M150-35S, M155-35S and averaged for each grade. Fig.1 shows the resulting relative difference $\delta P_{SE} = 100(P_{SST} - P_{EP}) / P_{EP}$ determined by the 6 contributors as circles, the different contrast of the fillings are assigned to different contributors. The continuous curve represents the least square fit to the older measurements [5] mentioned in section 2. and used as informative conversion factor in IEC 60404-3 [1]).

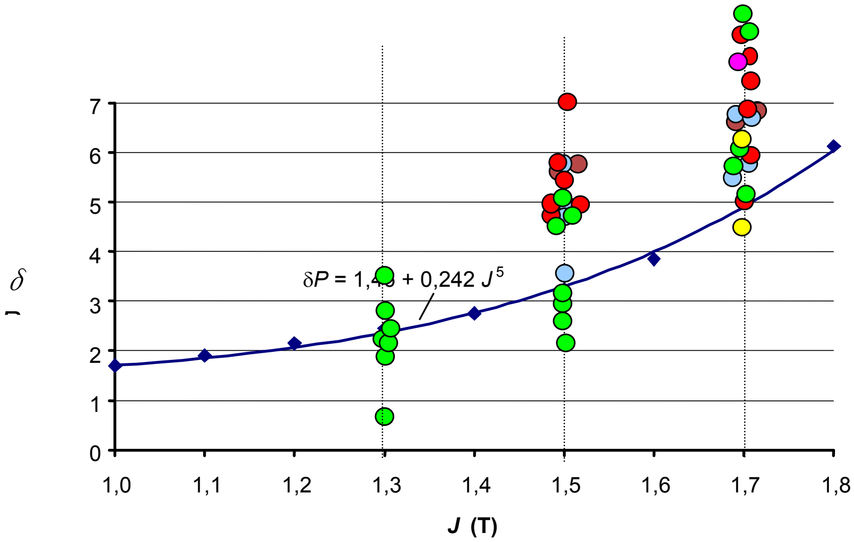

Fig. 1: Relative difference $\delta P_{SE} = 100(P_{SST} - P_{EP}) / P_{EP}$ (circles, new data from 6 industry labs.) versus magnetic polarization J, and the continuous curve δP representing the least square fit to the older measurements [5] used as informative conversion factor in IEC 60404-3 [1]).

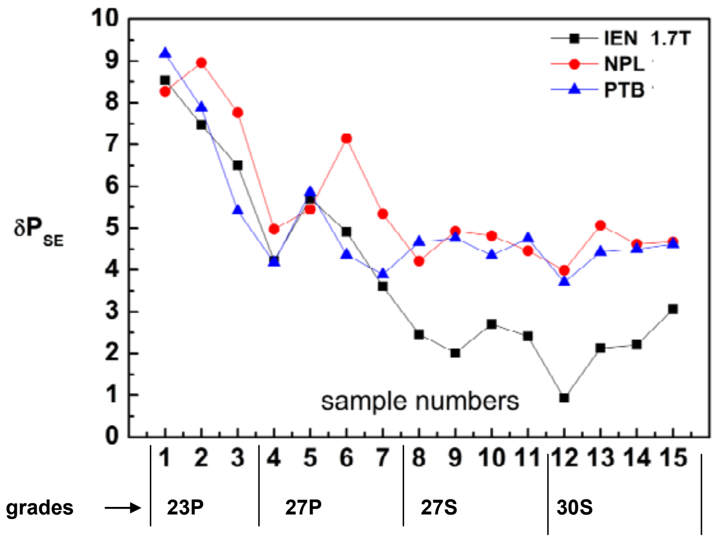

Fig. 2: Relative difference $\delta P_{SE} = 100(P_{SST} - P_{EP}) / P_{EP}$ measured at 1.7 T and 50 Hz at IEN, NPL, PTB on 15 related Epst-SST sample pairs of grades 90-23P, 103-27P, 130-27S and 140-30S

Similar to the results of the earlier studies [5], the δP_{SE} values show that the SST values are generally higher than the Epstein values, and that the relative and absolute differences increase with increasing flux density. This is, to the greater part, due to the systematic error introduced by the inhomogeneity formed by the Epstein frame corners. The contribution through the magnetic loss of the SST yokes depends considerably on their quality which is essentially determined through the interlamination resistance. The new results are higher than the old ones (continuous curve). This phenomenon was already stated earlier by some industry experts. A reason might be the difference in the yokes' quality since the yokes of the PTB-SST used for the former measurements were of high quality

[6]. Fig. 1 also shows considerable dispersion of the results appeared which is not really surprising under the aspect of different samples and different measuring set-ups. However, there is not sufficient knowledge about facts of details behind these findings to allow a safe interpretation. Below, experiments for progress in that direction are discussed.

4. Data exploited from earlier measurements at reference laboratories

One step in that direction might be to consider data measured earlier with high precision on 15 related g.-o. sample pairs by three European reference laboratories (IEN, Italy; NPL, UK; and PTB, Germany) [7] which have not been evaluated yet under the δP_{SE} aspect.

Correlation of the δP_{SE} values to grain-oriented material grades have not been found in earlier studies [1,8]. Fig. 2, however, shows at least a weak indication of this correlation. It seems that the δP_{SE} values show larger dispersion at magnetization states that are more below technical saturation, i.e. remain still in a more chaotic Barkhausen situation as it is the case in lower flux densities (not shown here) or with high permeability P-grades. On the other hand, in the more domain-wall free state of c.g.o. material in higher flux density, a remarkable agreement between two of the labs over the eight individual S-type sample pairs appears which is too striking as to be interpreted as a fortuitous event, although the reason for the systematic difference to the third lab is unclear.

5. Conclusions and possible further experiments

As also demonstrated earlier [5], the consideration of the relationship between Epstein and SST measurement results cannot go without the statistic aspect. Secure cognition is that, with grain-oriented materials, the related difference $\delta P_{SE} = 100(P_{SST} - P_{EP}) / P_{EP}$ is determined by a positive error of the SST and a negative one of the Epstein method and ends up at 5 % to 8 % at 1.7 T. Measurements with well defined conditions also allow the conclusion that there is a trend to higher δP_{SE} values with lower loss grades.

Under the aspect of the metrological and economical relevance of this problem it is desirable to achieve more knowledge of the details behind the presented findings so that the systematic and statistic errors of the Epstein and SST method can be analyzed and better understood. For this purpose further investigation of the practical dispersion situation of Epstein and of SST measurements through round robin tests should be undertaken. Moreover, the error sources of Epstein frame corners as well as those of SST yokes' defects should be clarified and, thus, their influence on the measurement results be analyzed.

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