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VOLTAGE FLUCTUATIONS MEASUREMENT — EXPERIMENT IN THE INDUSTRIAL ENVIRONMENT

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Summary: **At one of Polish steelworks there was carried out an experiment, which aim was measurement of voltage fluctuation parameters at the same point of supply network, by means of different measuring instruments, than on that basis assessment of credibility of ten selected flickermeters, available on the Polish market. All instruments were declared by the manufacturers as complying with the terms of the IEC 61000-4-15 standard Their indications however, differ significantly as the experiment has demonstrated.**

The authors do not assess the correctness of indications of specific instruments, rather conclude their substantial discrepancy. Obtained results indicate that the recommendations of IEC 61000-4-15 standard allow for construction of correct, i.e. complying with the standard, instruments which do not meet their primary metrological objective (comparison of measurement results). Normally a user of the instrument cannot evaluate himself the correctness of measurements while manufacturer's declaration does not guarantee their correctness, as the experiment has demonstrated.

Key words: voltage fluctuation, flicker, flickermeter, measurement

1. INTRODUCTION

At one of the Polish steelworks, at the substation denoted in Figure 1 as GST-6 was carried out an experiment, which goals were: (i) measurement of voltage fluctuation at the same point of supply network by means of different measuring instruments; (ii) comparison and analysis of the obtained results; (iii) comparing results of measurements obtained by means of the „own design"[1] instruments with those obtained using „market-available" instruments; (iv) assessment of credibility of selected flickermeters, available on the Polish market. Duration of the measurement was five hours, from 11:00 to 16:00. Instruments used in the experiment are listed in Table 1. All instruments were declared by the manufacturers as complying with the terms of IEC 61000-4-15 standard. Synchronisation of the measurements with different instruments was ensured by synchronisation of internal clocks of the instruments and computers employed in the experiment.

1.1. Description of the measurement point

The measurement has been carried out at bus-bars of the medium voltage (6 kV) substation in a measurement bay 2a, by means of voltage transformers. Magnitude of the secondary side voltage was $100/\sqrt{3}$ V (line-to-neutral). A motor, which is the cause of voltage fluctuations, is supplied from bay 3a. Diagram of the switchboard with the measurement point indicated is shown in Figure 1.

1) This description means the instrument has been designed and developed by the university or research institute.

Table 1. List of Instruments Used in the Measurements

No.	Type of instrument	Instrument symbol [1]	Owner of the instrument
1	Panensa MEF	P1	Technical University of Radom
2	Memobox 686 (LEM-Instruments)	P2	Technical University of Radom
3	Own design	P3	Technical University of Lodz
4	Own design	P4	Electrotechnical Institute, Gdańsk
5	Memobox 800 (LEM-Instruments) [2]	P5	SEMICON
6	Power Recorder 1650	P6	University of Mining and Metallurgy
7	Own design	P7	University of Mining and Metallurgy
8	Oscillostore P513	P8	Institute of Power Engineering, Katowice
9	Memobox 686 (LEM-ELMES)	P9	Energopomiar-Elektryka, Gliwice
10	Own design	P10	Gdynia Maritime Academy

1) Brand names of instruments are here under substituted by the symbols from Table 1
2) Software version: CODAM 1.0

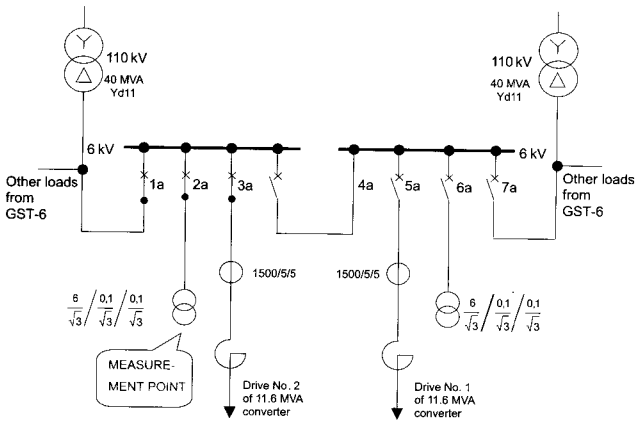


Fig. 1. Diagram of the Substation with Indicated Measurement Point

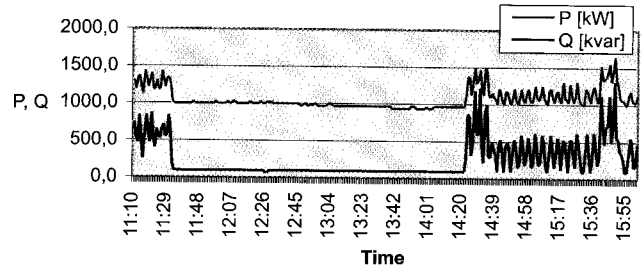


Fig. 2 Variation of the Mill's Drive Active and Reactive Power (P8)

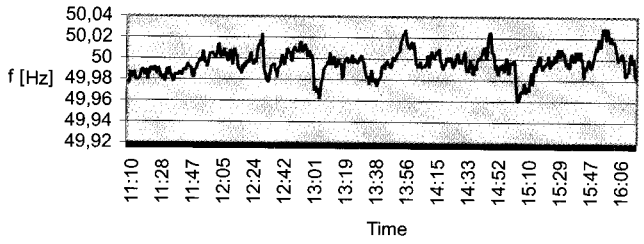


Fig.3. Frequency Variation During the Measurement Period (P6)

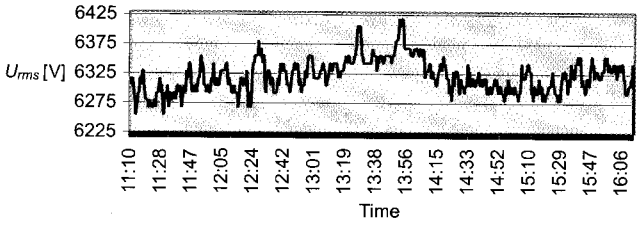


Fig. 4. The Voltage rms Value (P6) — min. = 6254V; max. = 6419V

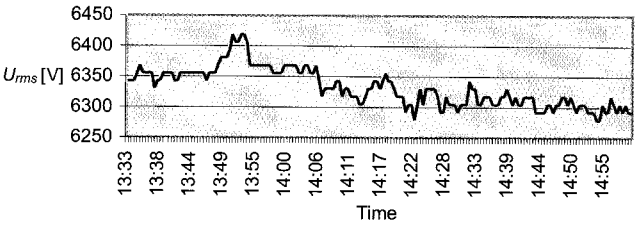


Fig. 5. The rms Voltage (the Mill Operating Under Load) (P6); min.—6279V, max.—6419V

1.2. Variation of the active and reactive power of mill's drive

Variation of the mill's drive active and reactive power is shown in Figure 2. Values of power updated in 1 minute interval.

After initial rolling (until 11:30) a break in the mill operation occurred until approximately 14:20.

2. POWER QUALITY AT THE MEASUREMENT POINT

2.1. Frequency variation

Frequency variations, shown versus time in Figure 3, were contained within the limits specified as permissible in EN 50160 standard during entire monitoring period (analogous results were obtained with all other instruments).

2.2. Variation of the voltage rms value

Characteristics of rms voltage variation: in the entire measurement period and during the mill's start are shown in

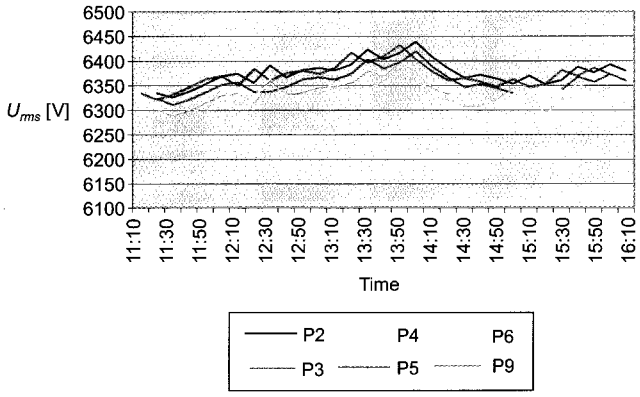


Fig. 6. Results of the Voltage rms Value Measurements

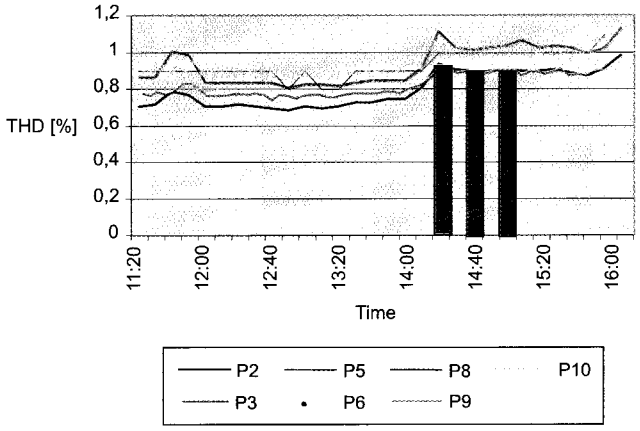


Fig. 7. Comparison of Results of Total Harmonic Distortion THD Measurements. Three Vertical Bars Indicate Results of Three Measurements of THD Obtained by Means of the Instrument P5

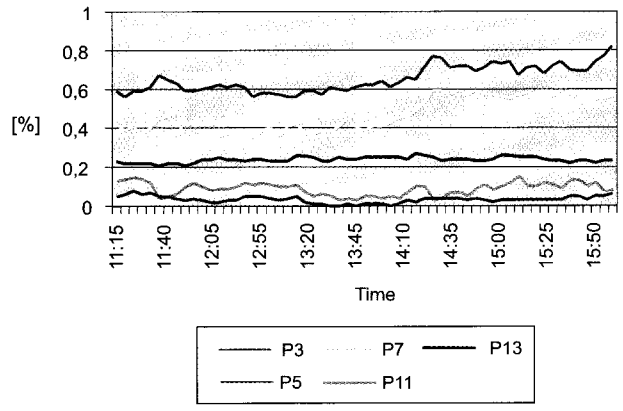


Fig. 8. Variation of the Voltage Dominant Harmonics (P9)

Figures 4 and 5 respectively. Voltage rms values were updated 30 s intervals.

Indications of all instruments used in the measurement of the voltage rms value are shown in Figure 6 for comparison. As the comparison shows they are approximate and maximum difference does not exceed 120 V.

2.3. Voltage distortion

Figure 7 shows characteristics illustrating THD fluctuation measured by means of different instruments (excluding P1, P4 and P7, not used in this measurement). From the presented characteristics it follows that the voltage THD limits (according to EN 50160) have not been exceeded. Two periods are clearly visible from the figure: the mill's idle run and operation periods. They also manifest themselves in changes of dominating harmonics values (Fig. 8).

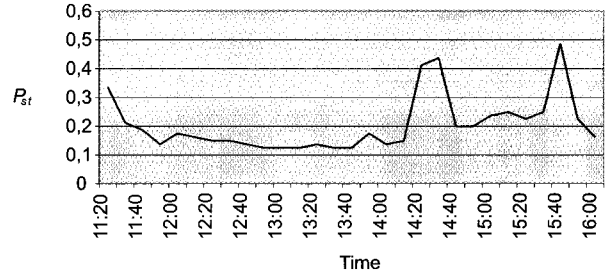


Fig. 9. Results of the Short Term Flicker Severity P_{st} Measurement with the Instrument P1; $[P_{st}]_{min} = 0.12$, $[P_{st}]_{max} = 0.48$

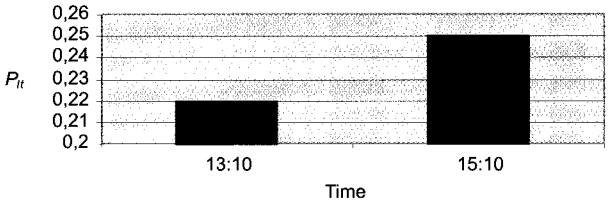


Fig. 10. Results of the Long Term Flicker Severity P_{lt} Measurement with the Instrument P1

3. RESULTS OF THE VOLTAGE FLUCTUATION MEASUREMENTS

Instrument P1 — Results of measurement are shown in Figures 9 (P_{st}) and 10 (P_{lt}). The break in rolling is clearly visible from the characteristic of this parameter.

The long term flicker severity attained the value of 0.22 after initial two hours.

Instrument P2 — Results of the measurement are shown in Figures 11 (P_{st}) and 12 (P_{lt}). Within the entire recording time, even during the break in rolling, the value of P_{st} did not decrease below 0.8 level. The long term flicker severity, measured with the instrument P2, attained value of 0.94 after initial two and next after four hours.

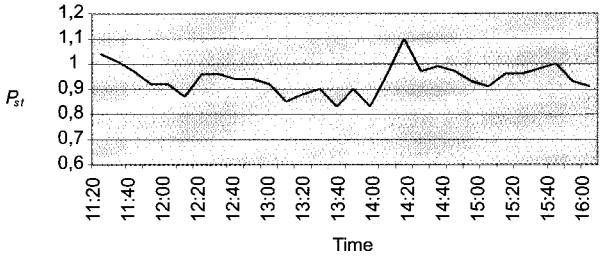


Fig. 11. Results of the Short Term Flicker Severity P_{st} Measurement with the Instrument P2; $[P_{st}]_{min} = 0.83$ (13:40 and 14:00), $[P_{st}]_{max} = 1.1$ (14:20)

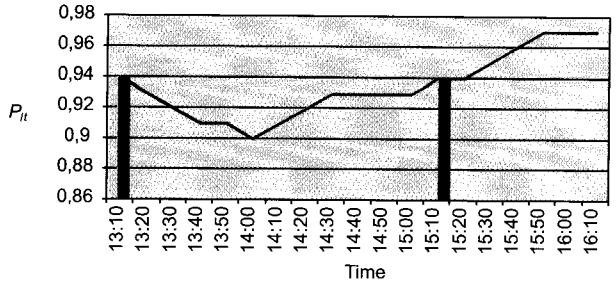


Fig. 12. Result of the Long Term Flicker Severity P_{lt} Measurement with the Instrument P2

Instrument P3 [5] — Results of measurement are shown in Figures 13 (P_{st}) and 14 (P_{lt}). The characteristic of the short term flicker severity, presented in Figure 13 demonstrates significant differences of the P_{st} values recorded during the mill's operation and during the break in rolling. There are also visible some changes in the P_{st} value between the subsequent cycles of the mill operation during the afternoon rolling.

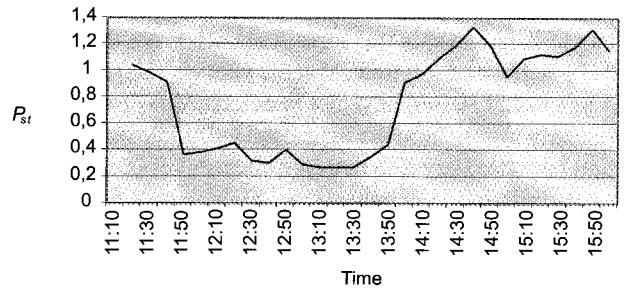


Fig. 13. Result of the Short Term Flicker Severity P_{st} Measurement with the Instrument P3; ; $[P_{st}]_{min} = 0.27$ (13:30), $[P_{st}]_{max} = 1.33$ (14:40)

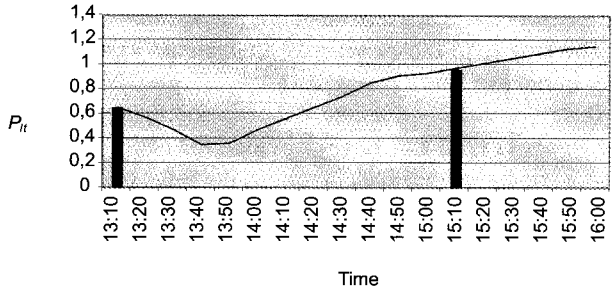


Fig. 14. Result of the Long Term Flicker Severity P_{lt} Measurement with the Instrument P3

Instrument P4 — Results of the measurement are shown in Figures 15 (P_{st}) and 16 (P_{lt}). The measurements made with the instrument P4 were of shorter duration and they were terminated at 14:20.

Instrument P5 — Results of the measurement are shown in Figures 17 (P_{st}) and 18 (P_{st}). Measuring with this instrument was interrupted at 15:00 and resumed at 15:30. From the characteristic presented in Figure 17 it follows that P_{st} was attaining large values during the entire recording time. Even during the break in rolling the value of P_{st} did not decrease below the 0.8 level.

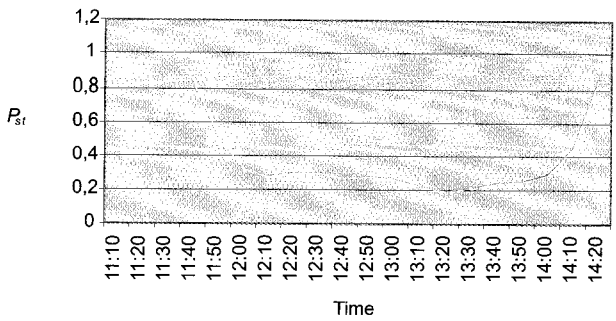


Fig. 15. Result of the Short Term Flicker Severity P_{st} Measurement with the Instrument P4; $[P_{st}]_{min} = 0.19$ (13:20), $[P_{st}]_{max} = 1.05$

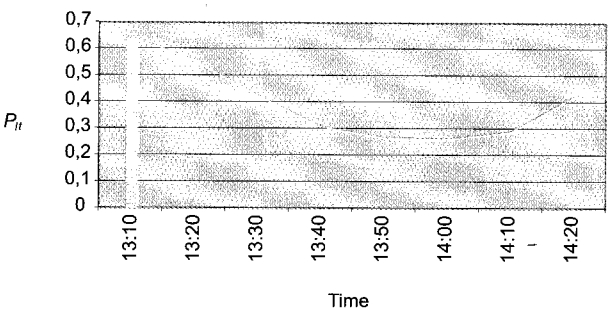


Fig. 16. Result of the Long Term Flicker Severity P_{lt} Measurement with the Instrument P4

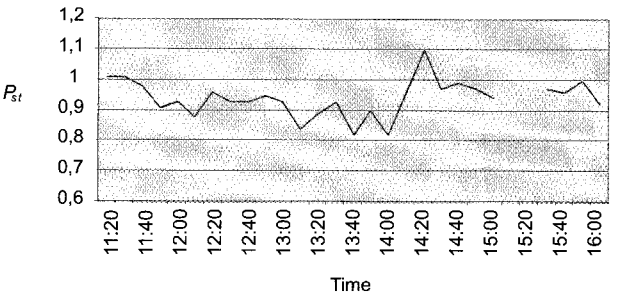


Fig. 17. Result of the Short Term Flicker Severity P_{st} Measurement with the Instrument P5; $[P_{st}]_{min} = 0.82$ (13:40 and 14:00), $[P_{st}]_{max} = 1.10$ (14:20)

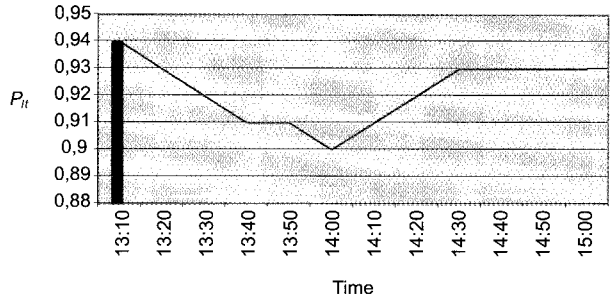


Fig. 18. Result of the Long Term Flicker Severity P_{lt} Measurement with the Instrument P5

Instrument P6 — Characteristics of P_{st} and P_{lt} parameters are presented in Figures 19 and 20. Instants of brake in the rolling (decrease in the short term flicker severity) and its resuming (increase of the P_{st} value) are clearly visible from the P_{st} characteristic shown in Figure 19. After resuming the mill operation an increase of flicker severity occurs and next decrease again to the similar level as during the mill idle (two periods of mill operation).

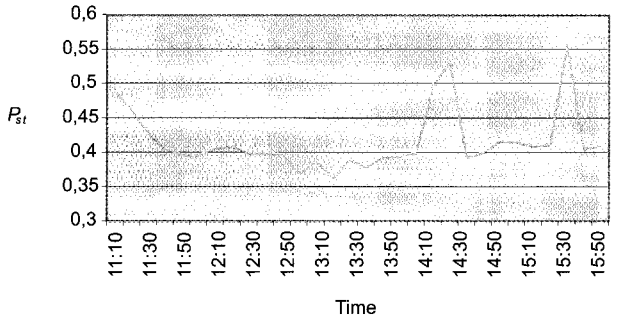


Fig. 19. Result of the Short Term Flicker Severity P_{st} Measurement with the Instrument P6; $[P_{st}]_{min} = 0.36$ (13:20), $[P_{st}]_{max} = 0.55$ (15:40)

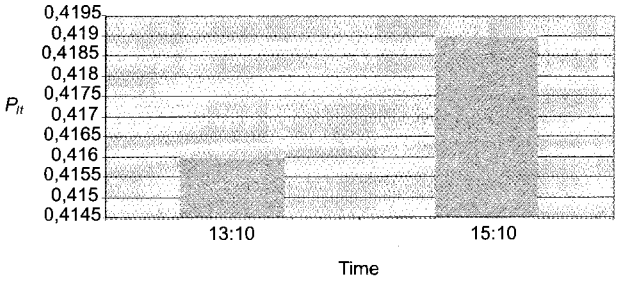


Fig. 20. Result of the Long Term Flicker Severity P_{lt} Measurement with the Instrument P6

Instrument P7 [1] — Figure 21 presents the P_{st} values recorded during termination and resuming of the mill operation. Measurement with the instrument P7 was interrupted at 12:20 and resumed at 14:45. The value of the parameter P_{lt} has not been determined.

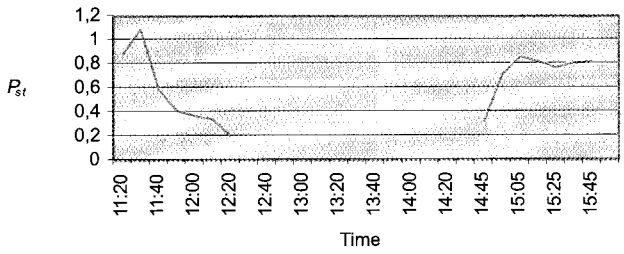


Fig. 21. Result of the Short Term Flicker Severity P_{st} Measurement with the Instrument P7; $[P_{st}]_{min} = 0.2$ (12:25), $[P_{st}]_{max} = 1.09$

Instrument P8 — Figures 22 and 23 show changes in P_{st} and P_{lt} values Instants of reduction of the value (break in rolling) and than of its increase (rolling resumed) can be visible. Another drop of the P_{st} value, recorded about 14:40, has its reflection in the time diagram of mill's load, illustrated also in Figures 24 and 25.

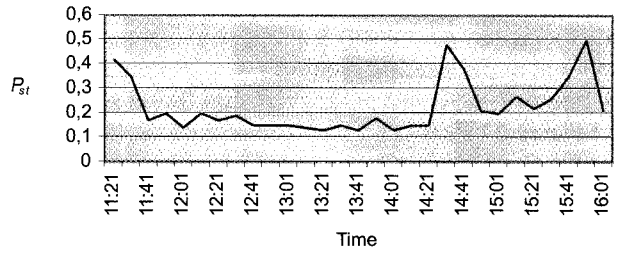


Fig. 22. Result of the Short Term Flicker Severity P_{st} Measurement with the Instrument P8; $[P_{st}]_{min} = 0.12$, $[P_{st}]_{max} = 0.5$ (15:51)

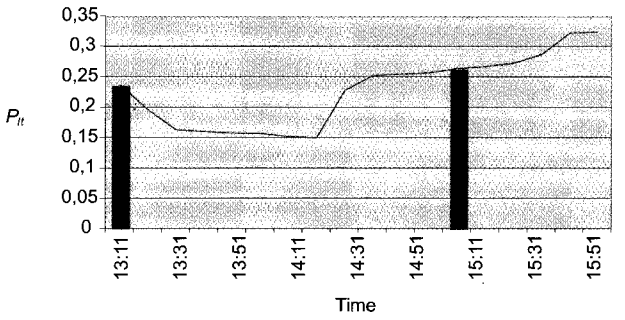


Fig. 23. Result of the Long Term Flicker Severity P_{lt} Measurement with the Instrument P8

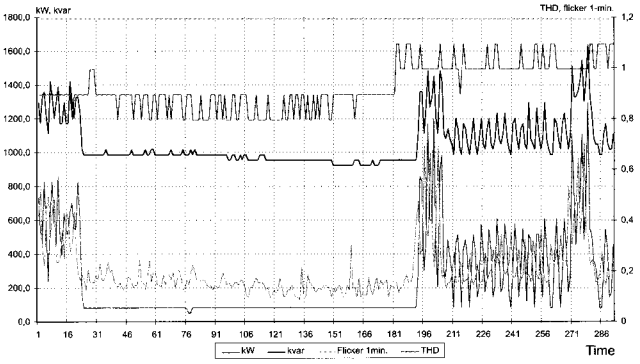


Fig. 24. Characteristics Averaged in 1 Minute Intervals (P8)

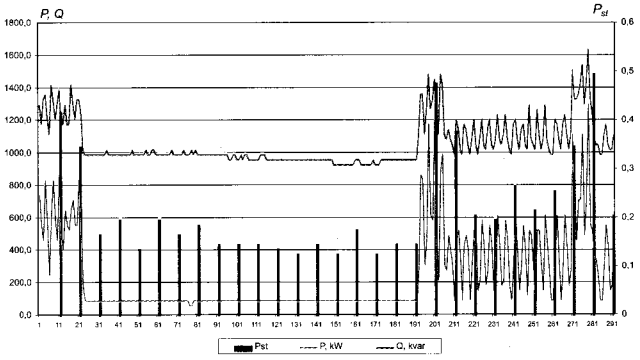


Fig. 25. Characteristics Averaged in 10 Minutes Intervals (P8)

Instrument P9 — In case of this instrument the short term flicker severity values are averaged in five-minutes intervals, not as the standard requires every 10-minutes. Figure 26 shows characteristic of the short term flicker severity P_{st} and Figure 27 shows characteristic of the long term flicker severity P_{lt}. Periods of brake in rolling (reduction of the P_{st} value) and resuming the rolling, which manifests itself by increase of the P_{st} value, can be clearly visible from Figure 26.

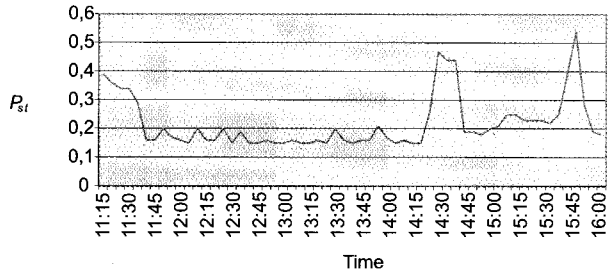


Fig. 26. Result of the Short Term Flicker Severity P_{st} Measurement with the Instrument P9; $[P_{st}]_{min} = 0.15$ (Several times), $[P_{st}]_{max} = 0.54$ (15:50)

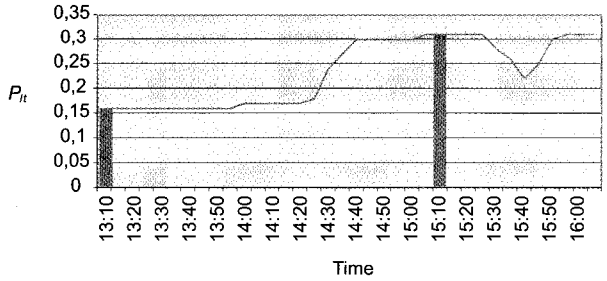


Fig. 27. Result of the Long Term Flicker Severity P_{lt} Measurement with the Instrument P9

Instrument P10 — Figure 28 presents results of the short term flicker severity in a restricted time interval: 11:20-12.10. The recording period includes the mill's brake and operation time, which is distinctly visible in the Figure. The P_{st} value was initially 0.46 and from 11:30 (brake in rolling) it began decreasing till 0.17 at 12:00.

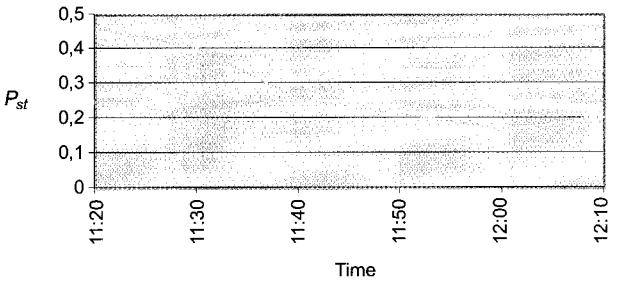


Fig. 28. Results of the Short Term Flicker Severity P_{st} Measurement with the Instrument P10

4. COMPARATIVE ANALYSIS OF THE VOLTAGE FLUCTUATION PARAMETERS

4.1. Comparison of the results from instruments P2, P5, P9—(Memobox)

Three instruments of *Memobox* 686 type were used in the experiment. Two of them (P2 and P5) were manufactured by LEM – INSTRUMENTS company, whilst the third (P9) by LEM – ELMES company. Figure 29 presents compared characteristics of the short term flicker severity as recorded with respective instruments.

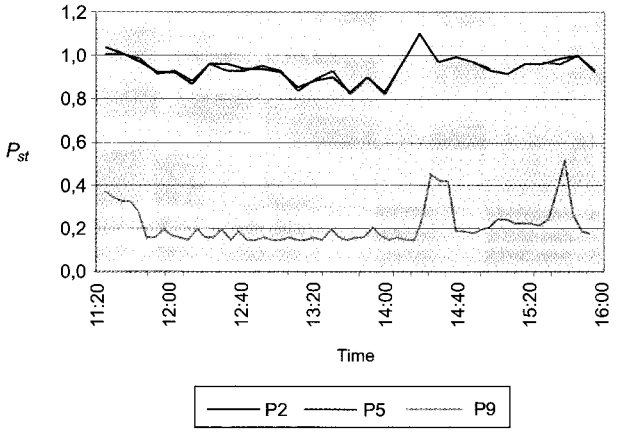


Fig. 29. Comparison of P_{st} Characteristics (P2, P5, P9)

The short term flicker severity P_{st} values, obtained as result of the measurement with instruments P2 and P5, are very similar to each other. For some instants they are almost identical whereas the values obtained from instrument P9 are significantly lower then others. According to indications of instruments P2 and P5 the values of P_{st} remained c.a. 0.9 during the brake in rolling. There is also no distinctive change of P_{st} during the mill idling and rolling in contrast to the instrument P9, where during the same period changes of P_{st} are twice as large.

Figure 30 gives comparison of long term flicker severity recorded with the instruments under consideration.

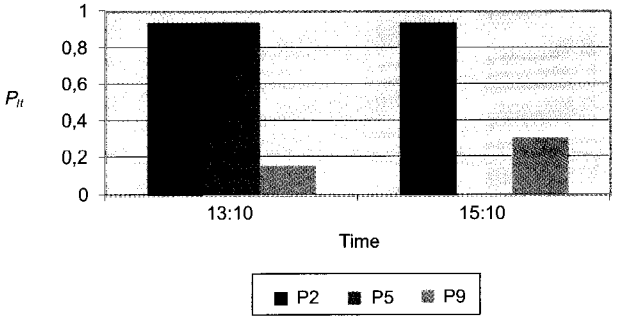


Fig. 30. Comparison of Measurement Results of P_{lt} (instruments P2, P5, P9)

Duration of the measurement with instrument P5 did not allow for evaluation of two values of the short term flicker severity. As follows from the presented comparison, in case of the instruments P2 and P5 the value of P_{lt} at 13:10 (after two hours measuring) amounted to 0.94. The result of measurement obtained with the instrument P9 differs significantly from the remaining and, what is characteristic, it has recorded the difference between two values of P_{lt}.

4.2. Comparison of P1, P6, P8 (Panensa-MEF, Oscilostore P-513 and Power Recorder)

Figures 31 and 32 present comparison of measurement results obtained from instruments manufactured by the companies, which offer their equipment on the Polish market. Figure 31 illustrates the comparison of P_{st}, and Figure 32 that of P_{lt}.

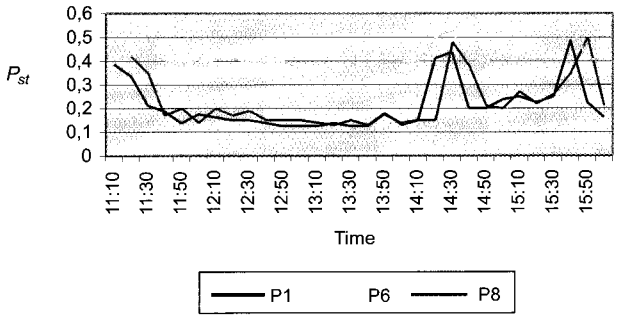


Fig. 31. Comparison of Measurement Results of P_{st} (instruments P1, P6, P8)

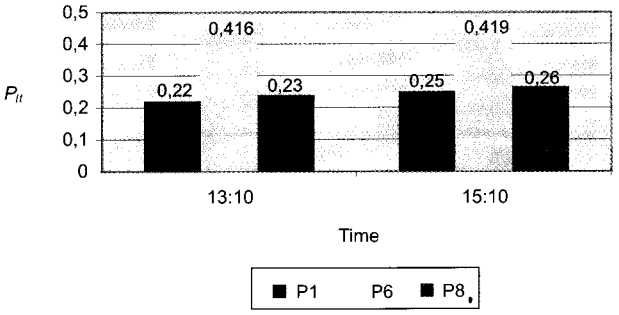


Fig. 32. Comparison of Measurement Results of P_{lt} (instruments P1, P6, P8)

From the comparison presented in Figure 31 it follows that characteristics obtained with instruments P1 and P8 are similar. During the mill operation and its idling both curves are close to each other. The result of measurement obtained with the instrument (P6) differs significantly from the others and during the entire measurement time it holds on higher level. P_{st} when measured with the instrument P6 attains significant values particularly during the mill's idle run.

Figure 32 gives a summarised comparison of long term flicker severity recorded with the instruments under consideration.

Comparison of the results shows that instrument P6 has measured the greatest value of P_{lt} while the remaining ones recorded slightly lower values. The common feature of all results from instruments under consideration is that the values P_{lt} obtained after initial two hours are slightly lower than those obtained after the next two hours.

4.3. Comparison of the „own design" instruments (P3, P4, P7, P10)

Figure 33 presents comparison of results of the short term flicker severity P_{st}.

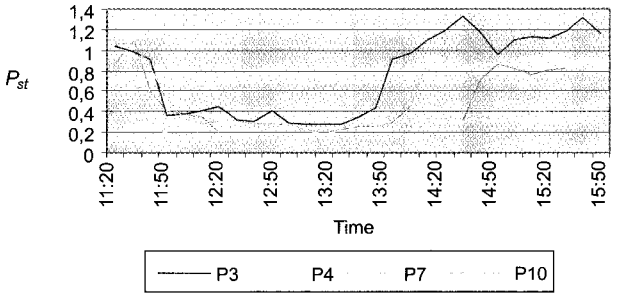


Fig. 33. Comparison of Measurement Results of P_{st} (instruments P3, P4, P7, P10)

The results shown in Figure 33 are of similar shape (except those of the instrument P10) in the initial and middle parts of the measurement period. Values of the short term flicker severity for all instruments were close to each other prior to unloading the mill and during its idle run. All instruments simultaneously recorded values exceeding the limit, which happened about 11:30. Quite different is the result of the measurement with the instrument P10. The values, obtained particularly in the initial recording period, differ significantly from the remaining results, while during the break in rolling (about 12:00) the values are closer. At 12:10 recording with instrument P10 was terminated. Discrepancy between the results from instruments, which continued the measurement, occurred when the mill run under load again. The instruments have registered an increase of the P_{st} values up to different levels. According to instrument P3 the limit value has been exceeded again and the short term flicker severity attained its maximum value of 1.33. Instrument P7 has recorded increase of P_{st} value to the level 0.86. Measuring with instrument P4 was interrupted.

Figure 34 gives a summarised comparison of the long term flicker severity recorded with the instruments under consideration.

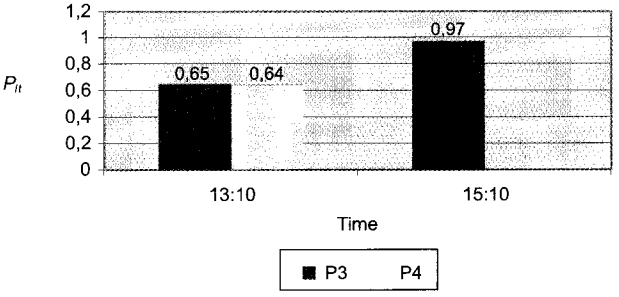
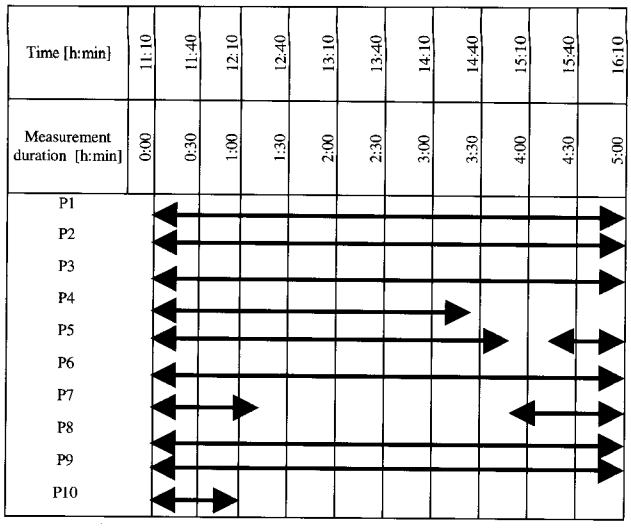


Fig. 34. Comparison of Measurement Results of the Parameter P_{lt}

Table 2. Use of the Experiment Time by Measuring Instruments



Duration of the measurement with instrument P4 did not allow for evaluation of two values of the short term flicker severity. As follows from the presented comparison, both instruments have measured the short term flicker severity value P_{lt} at 13:10 (after two hours of measuring) at similar level, whilst after the next two hours the value determined by instrument P3 is 0.97.

4.4. Comparison of all measuring instruments

Not every measuring instrument, intended for the experiment was used in the full measurement cycle. Use of the measuring time by the specific instruments is shown in Table 2.

The minimum and maximum values of the short term flicker severity P_{st} as measured with each measuring instrument are listed in Table 3, long term flicker severity values P_{lt} obtained after two and four hours of the experiment are listed in Table 4. Because of the partial use of the experiment time by instruments P7 and P10 no P_{lt} value was determined, and with instruments P4 and P5 only the values of P_{lt} after two hours of measuring were determined.

Graphical representation of the measurement results listed in Tables 3 and 4 is shown in Figures 35 and 36.

Figures 37 and 38 show comparatively all characteristics of short term and long term flicker severity. Characteristics in Figure 37 differ significantly. Beside the curves which attain their maximum at the value of c.a. 0.5 (P1, P6, P8, P9, P10) there are also such where minimum values do not exceeding 0.8 (P2, P5). The „own design" instruments displayed the greatest discrepancy in P_{st} values measured during the mill operation and idle run periods. From the performed analysis it follows that the least discrepancy show the characteristics obtained from the following instruments: P1 (Panensa MEF), P8 (Oscilostore P-513), P9 (Memobox 686 – LEM-ELMES). It should be noted that these instruments measured consistently also other quantities (THD and rms voltage). The results from instruments P2 and P5 (Memobox 686) show also a good repeatability, it is however striking that P_{st} attains such a large values while the mill runs idly.

Comparison of the long term flicker severity shown in Figure 38 contains results from instruments which either measured this magnitude or could evaluate it from the P_{st} measurement. As follows from the comparison the obtained values differ significantly; in the extreme case the difference exceeds 400%. Correctness or incorrectness of indications of the particular instrument could be judged from the coincidence of measured quantities i.e. *U, THD,* P_{st} with the mill operation mode.

Table 3. Minimum and Maximum Values of the Short Term Flicker Severity P_{st}

Instrument symbol	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
$[P_{st}]_{min}$	0.12	0.83	0.27	0.19	0.82	0.36	0.2	0.12	0.15	0.17
$[P_{st}]_{max}$	0.48	1.04	1.33	1.05	1.10	0.55	1.09	0.5	0.54	0.46

Table 4. Values of the Long Term Flicker Severity P_{lt} After Two and Four Hours of Measuring

Instrument symbol	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
$[P_{st}]_{min}$	0.22	0.94	0.65	0.64	0.94	0.42	-	0.23	0.16	-
$[P_{st}]_{max}$	0.25	0.94	0.97	-	-	0.42	-	0.26	0.31	-

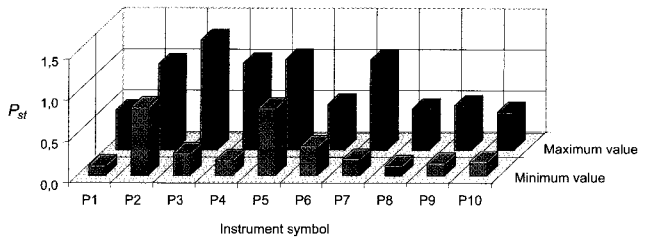


Fig. 35. Minimum and Maximum Values of the Short Term Flicker Severity P_{st}

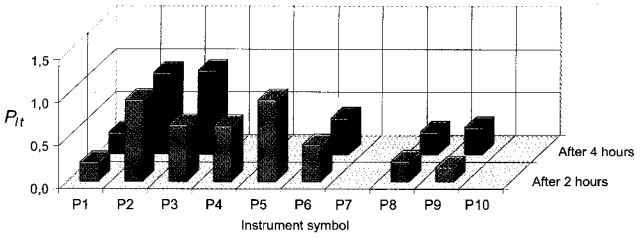


Fig. 36. Values of the Long Term Flicker Severity P_{lt} After Two and Four Hours of Measuring

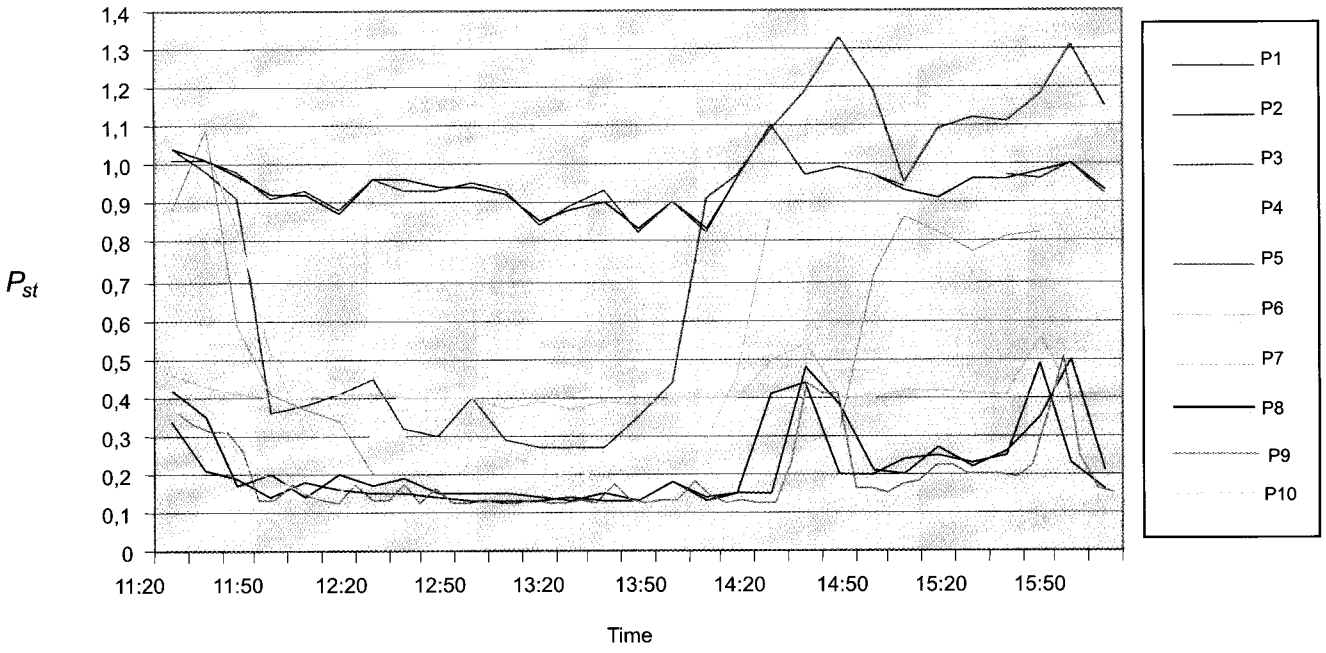


Fig. 37. Comparison of the P_{st} Obtained with All Instruments Used in the Experiment

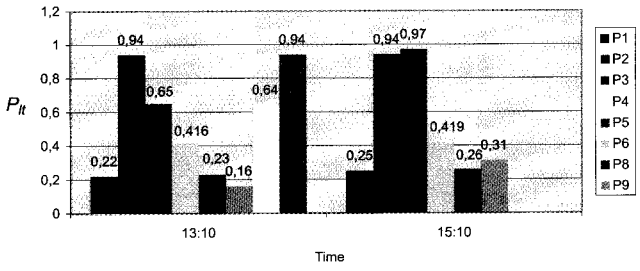


Fig. 38. Comparison of the P_{lt} Factors

5. CONCLUSIONS

All measuring instruments used in the experiment were declared by the manufacturers or designers as complying with terms of IEC 61000-4-15 standard. Although the instruments were measuring the same voltage signal at the same time, their indications differ significantly from each other.

The authors of the experiment do not assess the correctness of the specific instruments indications, rather conclude their substantial discrepancy. They point to the fact that recommendations of IEC 61000-4-15 standard are insufficient and allow for construction in compliance with this standard (and selling for heavy prices) of instruments which do not meet their primary metrological purpose i.e. comparison of measurement results. Normally a user of the instrument cannot evaluate the correctness of measurements, which could be the basis of dispute resolution between electrical energy provider and consumer, sometimes of serious financial consequences. And perhaps the very idea of such an instrument requires rectification?

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