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Application of optical diagnostics in high voltage engineering*

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Some examples of several optical methods applied in the Institute of High Voltages (IHV) of the Technical University of Warsaw to the studies of partial discharges (PD) and switching arc plasma (SAP) are reported and their practical usefulness and relevance proved.

1. Introduction

The researchers and engineers working in the field of high voltage (HV) technology and power engineering have been searching, for a long time, for the new methods of solving many scientific and technological problems.

The most advantageous are the methods provided by optical techniques and based upon detection and analysis of light accompanying different physical phenomena resulting from the working conditions of HV devices. The products of HV power industry, like: transformers, rotating machines, cables, insulators, switchgears and others, because of their dimensions, weight and price require a very specific approach either to their design or technology as well as to their service conditions. As the problems existing at present in HV engineering are very diversified and complex, only selected ones can be solved by application of optical methods in measurement and testing of HV device.

In this paper the authors aimed to present a practical application of several optical methods and their particular relevance to studies of partial discharges (PD) and HV switching arc plasma (SAP), in general, in an axial gas flow. According to the research programme which has been carried out in the Institute of High Voltages of the Technical University of Warsaw, this contribution presents the following applications of optical diagnostics:

— testing of a long time behaviour of insulating materials, used in HV technology, when stressed by high electric field and when so-called PD occurs,

— analysis of quenching-insulating gas-medium degradation caused by PD,

— investigation of temporal and spatial development of PD channels,

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** In alphabetical order.

— measurements of thermodynamical parameters of SAP and surrounding quenching gas flow,

— examination of electrode erosion phenomena.

2. Optical diagnostics of partial discharges

2.1. The significance of partial discharges

The most serious economic and technical problem in HV engineering is the degradation of dielectrics in the insulating systems of HV apparatus caused by PD. The PD are the electrical pulses initiated during the service by electrical stresses in every gaseous sphere, like: void, slit, crack or channel, etc, larger than few microns and existing practically in every insulator due to poor technology or to interaction of different working conditions (temperature, electrical and mechanical stresses, surroundings). The PD cause irreversible and accumulative damages of the insulation leading to the decrease of the reliability of the whole system and, moreover, to the pre-matured failure.

During the last two decades the studies of PD and their interactions with different dielectrics have been mainly made to assess the resistance to PD of such synthetic materials as polyethylene and epoxide resins. The studies were based upon accelerated aging of dielectric samples in different electrode-specimen arrangements with the source of PD. Two basic types of such arrangements are shown in Fig. 1a (open-gap arrangement — OA) and Fig. 1b (artificial void

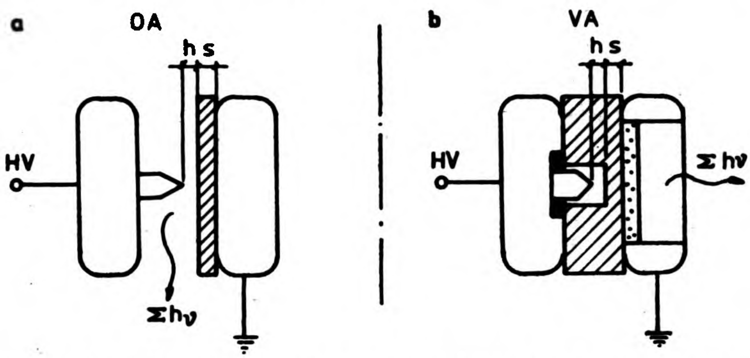


Fig. 1. Basic types of arrangements used during measurements: *h* — gap spacing, *s* — dielectric thickness

arrangement — VA). The PD pulses can be detected as an apparent charge by an electrical method. Most often the PD were studied electrically but our optical investigations have shown that an approach to the problem by dealing with the physical phenomena and degradation mechanism of PD under different test conditions is able to display many new results. The optical methods are more sensitive than the electric ones and, moreover, they represent a physical phenomenon different from its origin which can be used for the interpretation of PD [1].

2.2. Measurements techniques

The methods of detection and analysis of light resulting from PD are based upon physical processes accompanied by the emission, mainly in the UV and visible ranges during re-excitation and re-combinations of gas particles or breaking of electrons. Since the optical methods are mostly used for the study of degradation [2] and the author's results are published elsewhere [3], only the methods related to straight PD measurements will be reported here. Among these methods the most useful ones are photoelectric and spectroscopic analyses of light resulting from PD. Some of the other methods already described in [4, 5] will be only mentioned briefly.

The measuring techniques employed for optical analysis of PD are listed below.

2.2.1. Fast oscilloscopy of PD

In the spectral range from 300 to 600 nm the temporal development of discharges (avalanche or streamer type) was studied. In particular, the so-called anomalous discharges, not yet recognized but reported [4], were recorded and their significance was pointed out [6].

2.2.2. Image intensifier studies of PD

By this method a spatial development and localization of PD can be described and their relations to the breakdown test results can be analysed.

These studies have confirmed some hypotheses formulated according to the other degradation experiments [7].

2.2.3. Photoelectric and spectrographic measurements of PD

These measurements required some basic elements for setting-up the measuring systems with: photomultiplier, shutter, scanning monochromator, multichannel analyser, and spectrograph. In these systems different spectral characteristics of PD light vs. different parameters such as high voltage level, exposure time (t) and the type of dielectric material can be obtained and then analysed. These measurements and their results are described below in Chapter 2.3.

2.3. Spectral analyses of PD

The basic set-up for either photoelectric or spectrographic measurements is shown in Fig. 2. Photoelectric measurements were carried out in the wavelength range of 180–700 nm. The first identification of spectra of different PD sources was performed by scanning of the wavelength interval using medium-grating monochromator. An example of spectrum obtained for an artificial-void arrangement with epoxy resin (EP) sample is given in Fig. 3, where light intensity is plotted vs. the wavelength $J = f(\lambda)$.

The most common method of PD intensity photoelectric measurements are recordings of the light pulses density rate distributions (number of pulses (N)) vs. their amplitude (q) by a multichannel analyser. The measurements of distribution of polychromatic or monochromatic light pulses [$N = f(J_\lambda)$] were not so common [8], and no method was proposed for analysis of monochromatic light of PD at particular spectral range. Such intervals were earlier revealed on spectral graphs (Fig. 3). The set-up for light pulses density distri-

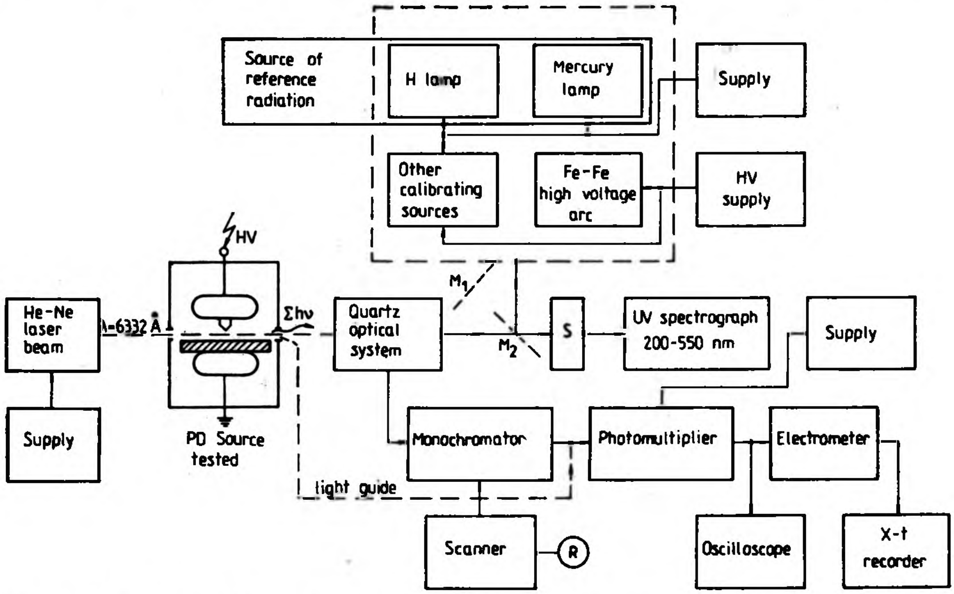


Fig. 2. Set-up for photoelectric and spectrographic measurements: M_1 — plane mirror, M_2 — half-transparent mirror, S — focal plane shutter, R — motor

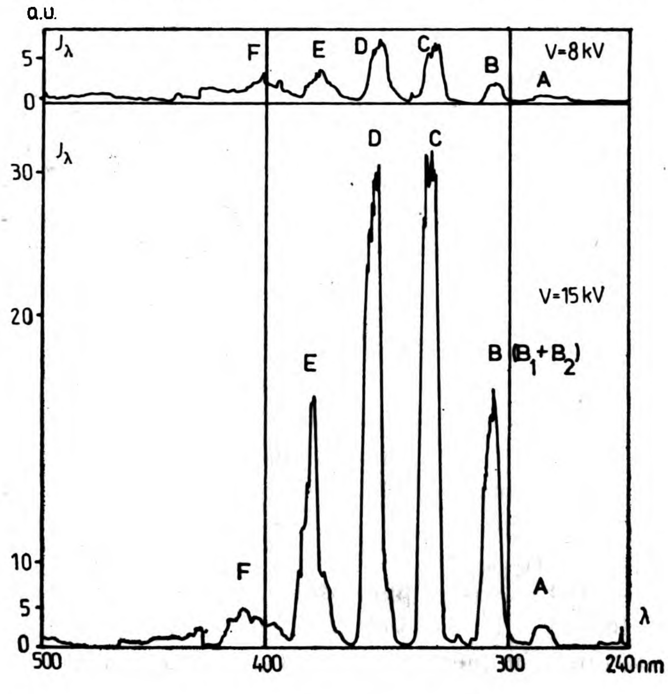


Fig. 3. Spectra of PD obtained by photoelectric method with spectral intervals of large intensity, here marked by the capital letters: A, B, C, D, E, F (B_1, B_2 — see Fig. 7)

bution $N = f(J_\lambda)$ for both poly- and monochromatic light is displayed in Fig. 4. Some examples of distribution of monochromatic light pulses emitted by PD in OA and VA are shown in Fig. 5. Figure 5a shows the changes of $N = f(J_\lambda)$ characteristics in the spectral range of B interval for PD source

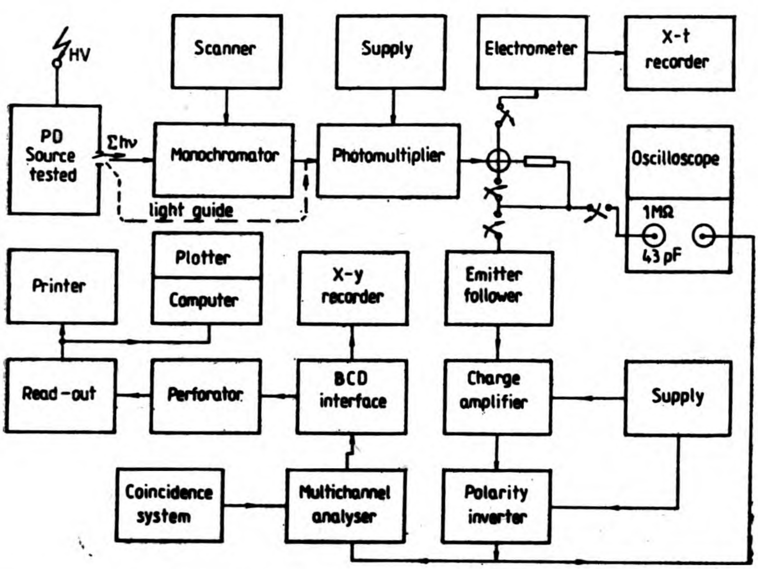
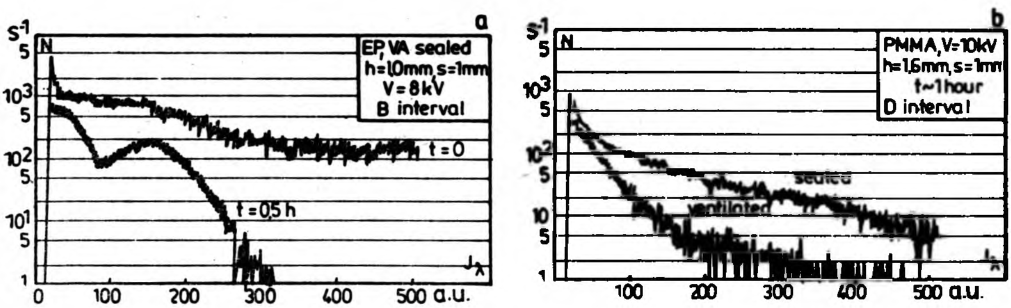


Fig. 4. Set-up for light pulses density measurements. Computing part of this system was realized by authors at Salford University in England



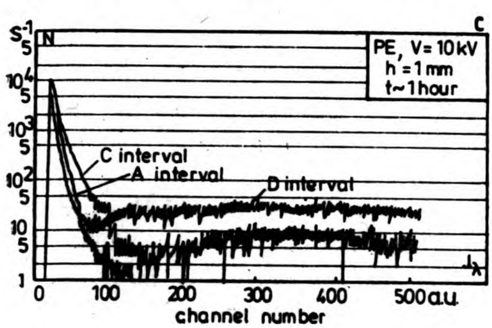


Fig. 5. Density distribution $N = f(J_\gamma)$ of monochromatic light pulses: A interval — 3339–3371 Å, B interval — 3500–3576 Å, C interval — 3671–3804 Å, D interval — 3894–4059 Å

in artificial void in epoxy resin sample at the HV level of 8 kV. Figure 5b displays the influence of sealing the void in organic glass (PMMA) sample at 10 kV level on the $N = f(J_\lambda)$ characteristics in the spectral range of D interval. Figure 5c shows the $N = f(J_\lambda)$ characteristics in OA with polyethylene (PE) sample recorded at 10 kV level for three different spectral intervals (A, C and D).

All these distributions enabled to analyse the changes of frequency and magnitude of PD during aging as a function of different parameters [8, 9].

As the usefulness of the photoelectric method is limited due to relatively poor spectral parameters of devices used, the more advanced interpretation of PD can be achieved by spectrographic method. The spectral measurements were carried out at the range from 200 to 500 nm and pictures were taken on ORWO UV–1 and AGFA BLAU plates. The calibration was done by means of iron standard arc and mercury or hydrogen spectral lamps. Photographed spectra (see an example displayed in Fig. 6) were next analysed in semiautomatic system [10] in which the value of the plate blackening was converted into electrical signal or, if necessary, into resulting emission coefficient via transverse-radial Abel transformation.

Fig. 6. Contact print of spectral plate with the results of spectrographic recordings for OA: 1, 3, 5 – molecular bands of PD spectrum (1 – U = 4.2 kV, 2 – auxiliary Hg spectrum, 3 – U = 3.5 kV, 4 – calibration spectrum of an arc between iron electrodes, 5 – U = 3 kV)

Figures 7a, b show some examples of the spectra obtained in OA. Figure 7a gives the spectrum of discharges between two metal electrodes at 3 kV level with no dielectric sample and Fig. 7b shows the spectrum of PD at 15 kV level in the arrangement with epoxy resin plate. Figure 7c gives a graph of expanded fragment of spectrum from Fig. 7a. Test conditions are marked on the drawings.

The harmonic oscillations of separate molecular bands reveal the presence of the oscillating and rotating components besides the electronic one. The other advantage of spectral analysis of PD performed by this method is the possibility of spatial visualization of radiation in the gap tested. An example of a spatial distribution of radiation of monochromatic light in the OA with no sample at 3 kV level and with epoxy resin sample at 15 kV level is shown in Figs. 8a and 8b.

To recognize the optical area of PD a static photography with equidensitometric analysis of pictures is usually employed as well as TV monitoring for PD development observation. To get the quantitative data relating to amplitude distribution of PD radiation pulses, the automatic-control measurement

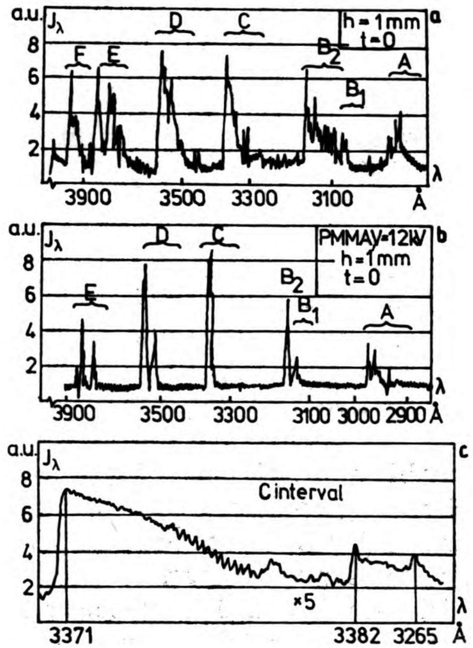


Fig. 7. Spectrograms of PD: a, b — two different sources, c — magnified (5 ×) fragment of C interval wing from spectrum displayed in Fig. a. A, B_1, B_2, C, D, E, F — denotation of main molecular bands (intervals)

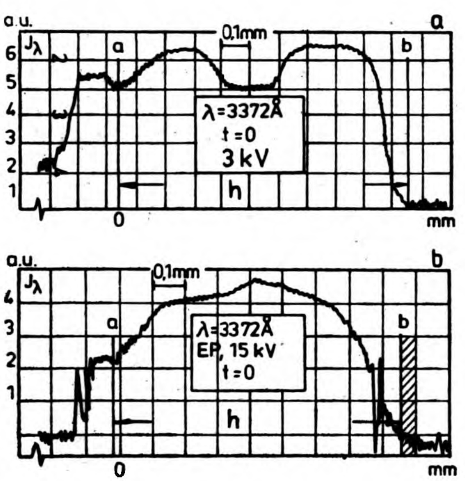


Fig. 8. Spatial distribution of radiation intensity in OA along the axial distance between electrodes (a — position of point electrode, b — position of plate electrode)

system based on the equipment of STANDARD 70 system is developed. This system will also enable a continuous measurement of a period (T_p) or mean frequency (ω_p) of periodic or non-periodic PD radiation pulses.

3. Optical diagnostics of HV apparatus

3.1. Switching arc plasma

In general, the switching arc plasma occurs when loaded electrical circuits are switched-off by a special electrical apparatus, e.g., by HV circuit-breaker. A serious problem in HV technology is that specific design and manufacturing of a new construction of HV equipment are required. To produce reliable power circuit-breakers such that all the electrical circuits be failure-free switched-off, the design methods would always require a model of plasma expected. At present such a model may either be phenomenologically assumed or formulated on the base of experimental results obtained during particular investigation of a real or prototype construction.

Theoretical approach, i.e., mathematical description of SAP behaviour may be of a substantial advantage in design and manufacturing processes, nowadays, however it is not yet easily applicable, hence, this problem requires a very urgent solution. To this end the necessary analytical formulae have been constructed based on the knowledge of quantitative data about plasma and quenching medium parameters.

The real behaviour of the switching axially blown arc plasma which is representative of HV circuit-breaker can be fully recognized only when many of SAP parameters are measured at high current level. The measurements of the gas flow parameters are of importance since they can determine the other important properties required for SAP model formulation. Our measurements are then focussed on determination of the species, density, temperature, chemical composition and geometry of arc column and the surrounding gas flow. It should be underlined that SAP is characterized by quite different properties, compared with those of low temperature pure laboratory plasma. The arc column being superimposed upon the underexpanded jet structure and strong cooling gas flow is then described by a time-unstable and non-uniform spatial distribution of its parameters. Moreover, the influence of a variable electric field, a complex interaction between arc column, surrounding sonic flow field and surfaces of electrodes, as well as the occurrence of possible plasma oscillations, shock waves, etc, much complicate the picture of such a plasma. Thus, the final aim of the model tests of HV circuit-breaker is [11]:

— to establish some strict principles for limiting parameters of quenching chamber determination from tests performed on the model having reduced dimensions under reduced arcing conditions and forced flow of quenching medium,

— to develop the calculation methods for quenching chamber design, suitable for different extinction techniques.

3.2. Measurements techniques and results

3.2.1 High speed photography (HSP)

Pentazet 35 camera enabling a 35,000 frames per second and Hyspeed Hadland camera (10,000 f/sec) were used for both poly- or monochromatic high speed photography of SAP. With the help of this equipment the following quantities can be determined:

— spatial and temporal shape and optical diameter of arc column,

— spatial radiation distribution within the arc and surrounding flow field,

— gas flow velocity.

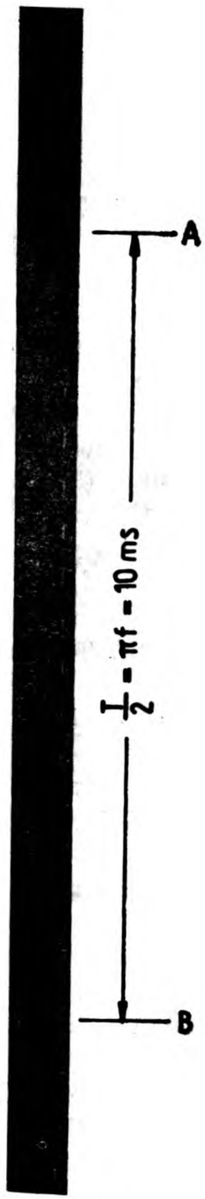
The HSP makes also possible a qualitative estimation of turbulence and convection phenomena in the boundary layer, likewise the magnetic pinch-effect within the plasma column. If necessary the stereoscopic pictures (90° angle projection) were taken to check the plasma and detect the contacts erosion.

As an example, the sequence of polychromatic pictures (30,000 f/sec) of free burning arc developing outside the nozzle of medium-voltage disconnector is presented in Figs. 9a–c [12]. The frame in Fig. 9c displays the SAP column shape at the moment close to successful extinction.

Figure 10 shows a part of temporal changes of monochromatic diameter of SAP. The pictures were taken (1700 f/sec) via quartz monochromator with transverse projection of particular cross-section of SAP on the entrance slit. The arc was struck in longitudinal electrode configuration with axial gas flow shown in Fig. 19. The lack of blackening (points A, B in Fig. 10) correlates with alternating current zeros. In densitometric analysis of pictures, use was made of photometric system [10] shown in Fig. 11. To control and visualize photometric processing the x-t logarithmic recorder is usually connected to the outputs of microphotometer or A/D converter fitted out with second analog monitoring after digital conversion. The resulting plots of monochromatic diameter of SAP are displayed in Fig. 12.

In order to control the SAP behaviour inside the quenching nozzle, the reduced in size model of nozzle was fitted with seven Pyrex windows (Fig. 13). The sequence of arc shapes in different cross-section of the nozzle is presented in Fig. 14.

To observe the SAP formation in HV-circuit breaker, several HSP measurements were done for different wavelengths. The pictures were taken with the aid of neutral and interference filters and high speed camera. The results of densitometric analysis of the pictures presented in Fig. 15 are represented graphically nearby, in form of the equidensitometric maps of optical region of SAP in air, obtained by taking account of the equal blackening degree (Z) criterion [13].



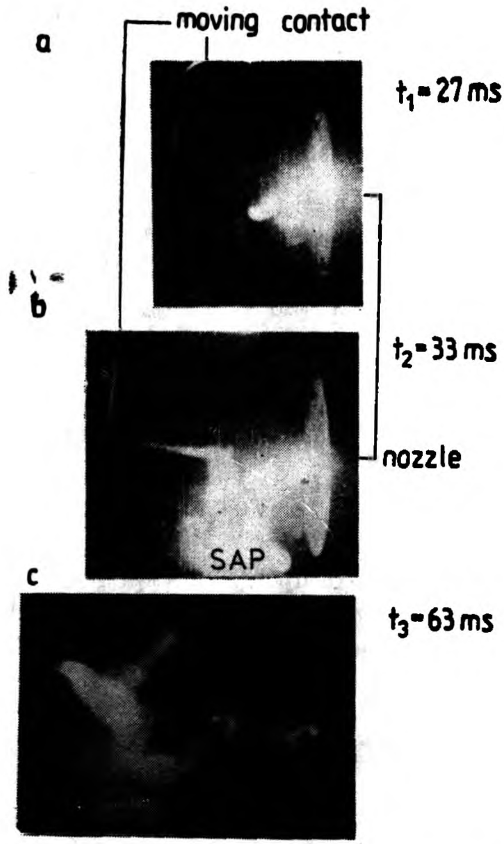


Fig. 9. Plasma development in medium-voltage disconnector. Exposure time — 33 μs (t_1, t_2, t_3 — time after contacts separation)

Fig. 10. Temporal development of monochromatic diameter λ = 555 nm of SAP in medium-voltage disconnector. Exposure time — 235 μm (A, B — first and second current zeros, respectively, T — period of current oscillations)

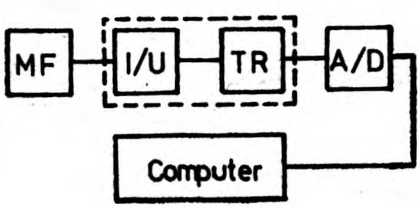


Fig. 11. A block-diagram of semi-automatic photometric system: MF — microphotometer, TR — tape recorder, A/D — analog/digital converter, Hewlett-Packard HP 9825 A computer

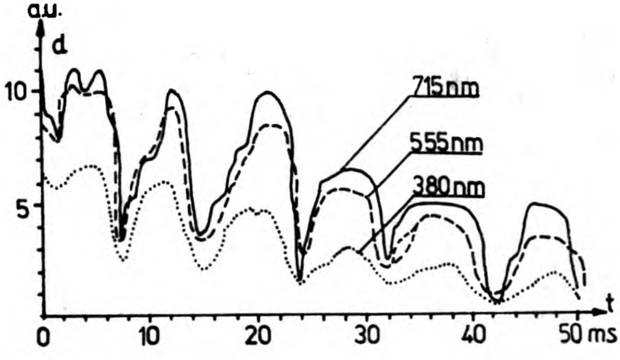


Fig. 12. Temporal plots of monochromatic diameters d (in arbitrary units) of switching arc plasma for decaying sineshaped current wave typical for prolonged short-circuiting test

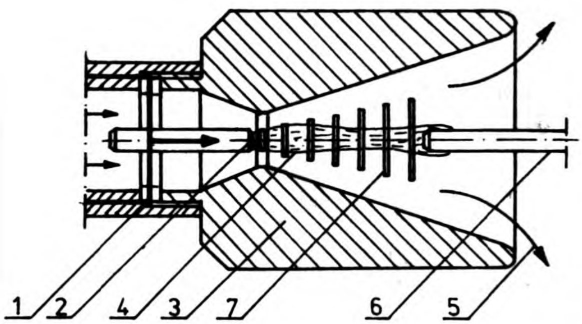


Fig. 13. Quenching nozzle model for observation of SAP inside the nozzle: 1 — current path, 2, 6 — electrodes, 3 — teflon nozzle, 4 — SAP, 5 — gas flow, 7 — Pyrex windows

Fig. 14. Visualization of arc behaviour in different cross-sections of the nozzle from Fig. 13 (a — internal part of the nozzle, b — outlet, c — external area). Exposure time — 33 μs

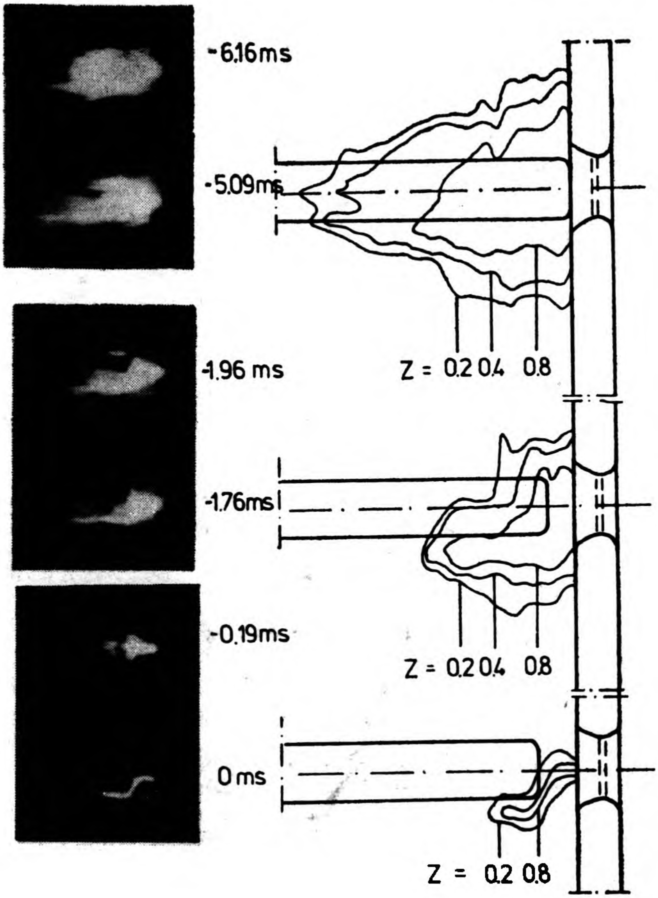


Fig. 15. SAP extinction in HV-circuitbreaker and resulting equidensitometric maps. Exposure time — 77 μs, t (ms) — time to current zero. Z — blackening degree

3.2.2. Schlieren technique

This method was applied by the authors to quantitative determination of plasma parameters within the plasma column, to visualize thermal, conductive and boundary layer plasma radii and to examination of plasma surrounding. From the density distribution $\varrho = f(r, z, t)$ the temperature profiles within the arc surrounding may easily be calculated. Thermal and boundary layer radii can be determined via temperature field function $\left(T = f(r, z, t)\right)$.

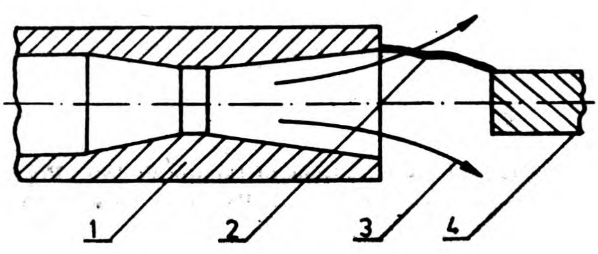


Fig. 16. Cross-section of a model mono-blast system: 1 — nozzle, 2 — breakdown channel, 3 — gas fow, 4 — electrode

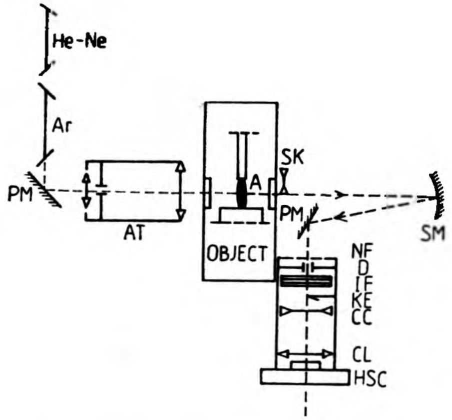


Fig. 17. Optical scheme for Schlieren system: PM — plane mirror, AT — autocollimating telescope, SK — standard condenser, SM — spherical mirror, NF — neutral filter, D — diaphragm, IF — interference filter, KE — knife edge, CC — correcting condenser, CL — camera lens, HSC — high speed camera, A — arc, He-Ne — auxiliary laser lamp for optical elements alignment, Ar — argon laser

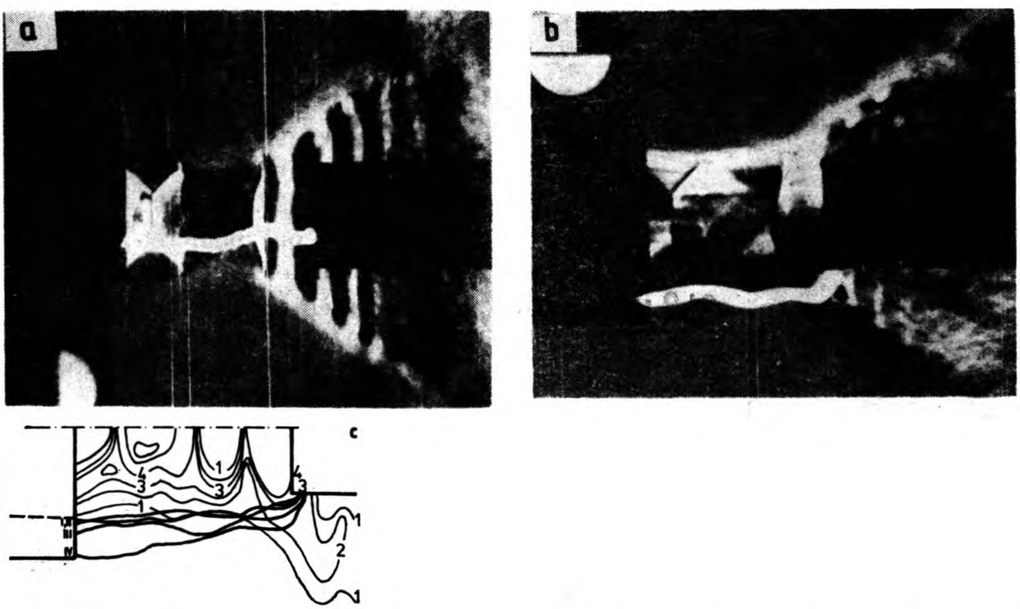


Fig. 18. Results of Schlieren measurements of sonic gas flow in the presence of electrical discharge: a — qualitative picture, b — quantitative picture, c — exemplary map of gas density distribution obtained from Schlieren pictures. 1, 2, 3, 4 — relative equidensitometric profiles of gas. I, II, III, IV — different breakdown channels, respectively. Exposure time — 50 μs

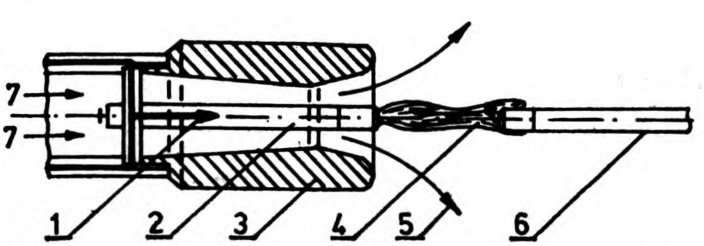
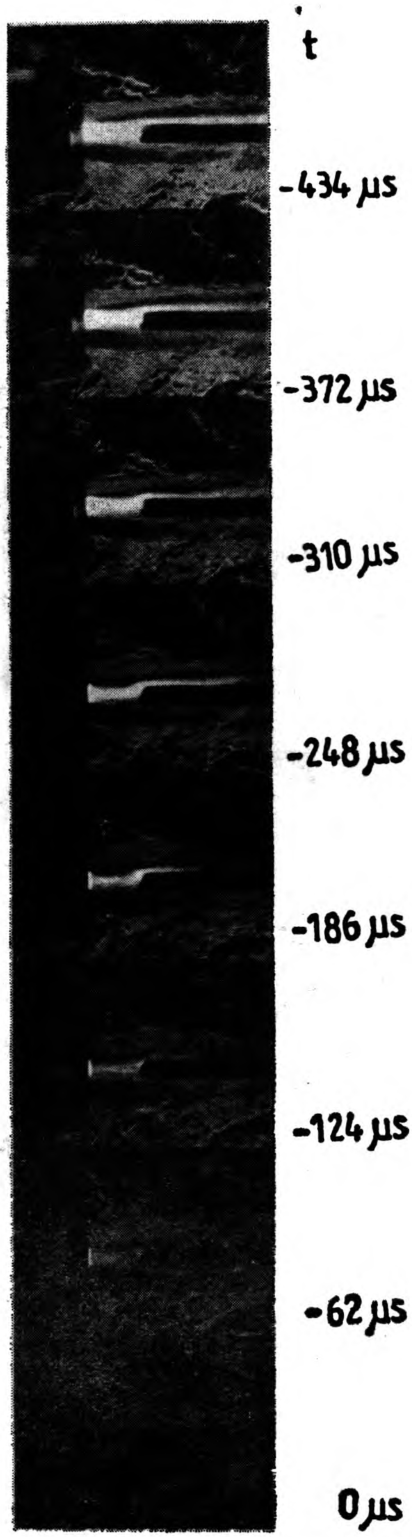


Fig. 19. Cross-section of quenching chamber nozzle model. Denotations — see Fig. 13



The other important information about the possibilities of shock waves formation and ignition strength of a monoblast quenching system (see, e.g. Figs. 16 or 19) are achieved by help of Schlieren system presented in Fig. 17. This arrangement enables us to obtain the qualitative (Fig. 18a) and quantitative (Fig. 18b) pictures of the nozzle-interelectrode gap-electrode area with distinctly marked breakdown channels [14]. The computed mapping of instantaneous equidensity profiles (Fig. 18c) reports a statistical character of breakdown channel location. Visualization of these areas made it possible to fix the places with smaller mechanical strength in the presence of sonic gas flow and qualified thermal strength in the presence of SAP.

The sequence of Schlieren pictures taken in the model of circuit-breaker quenching chamber (see Fig. 19) is presented in Fig. 20 [15]. Note an asymmetrcial plasma flow along the moving contact.

Fig. 20. Schlieren pictures of gas flow in the presence of decaying SAP. Exposure time — 62 µs (t – time to current zero)

3.2.3. Spectrography

A use of spectrographic recording system settled according to the scheme shown in Fig. 21 allows us to derive the following important in SAP analysis, quantities:

- radial temperature distribution $T = f(r)$,
- electron number density distribution $N_e = f(r)$,
- relative number of electrodes impurities.

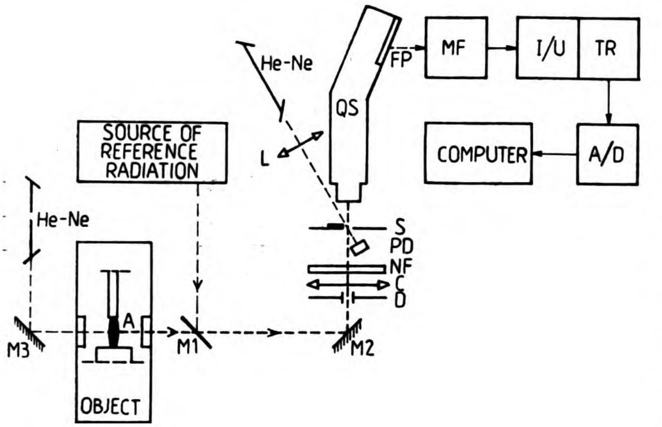


Fig. 21. Optical lay-out for spectrographic recording. A — arc, QS — quartz spectrograph, M1 — half-transparent mirror, M2, M3 — plane mirrors, D — diaphragm, C — achromatic double condenser, NF — neutral filter, PD — photodetector, S — focal plane shutter, He-Ne — positioning and shutter controlling laser lamps, L — glass lens, FP — photographic plate. Other denotations as in Fig. 11

Having the photographed spectra, the monochromatic density distribution across the arc and its surrounding were usually derived and then the optical area of arc column was determined.

If necessary the conditions for thermodynamic equilibrium of plasma are checked by analysis of monochromatic intensities distribution, e.g., by Boltzman plot method. Several results chosen from different spectral measurements are presented in Figs. 22–27 [16].

3.2.4. Spectrometry

The spectrometric system shown in Fig. 28 was employed for recording of temporal temperature distribution during switching-off operation. This system gives a possibility to carry out two-lines intensity detection outside the nozzle. Transmission and detection of single lines or integrated wavelength intervals intensity can be also possible by employing a suitable light guide from the interesting points of HV apparatus. If a special attention is paid to calibration of this system, the relative radiation power disengaged by plasma may be readily obtained. In all spectrometric measurements time-resolved monochromatic intensities are either recorded on loop-oscillograph or directly inserted to the digital computing units.

Due to strong dependence of emission coefficient vs. temperature and necessity of simultaneous measurements in steady-state phase likewise at current-zero period, processing of electric signals from photomultipliers with such a wide dynamic range requires a precise data compression. For that task a two-channel ampli-log module was employed for logging in 120 dB range [17].

3.2.5. Interferometry

A spatial density distribution within the plasma surroundings is studied by applying optical interferometric Mach-Zehnder system (Fig. 29) equipped with Ar-laser. To illuminate the whole interferometer aperture, the laser beam was expanded with an inverted telescope. In order to obtain the required scanning, a special two-staged electronically controlled shutter system was employed. The interferograms were photographed with a standard camera equipped with an appropriate lens system. The SAP radiation was eliminated by applying a narrow-band interference filter and small pinhole, both placed close to the focus of the camera telescope. The exemplary results related to the studies of cold gas flow and to core plasma visualization are presented in Fig. 30 [18].

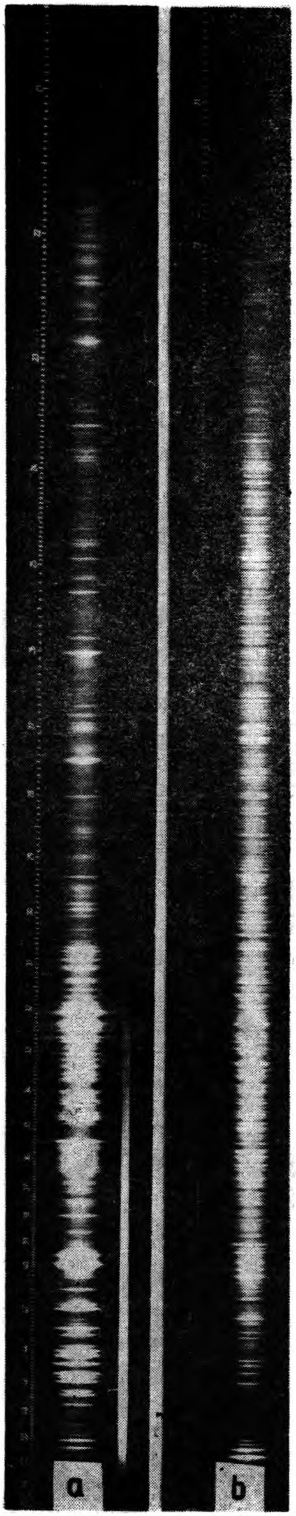


Fig. 22. Examples of high voltage SAP spectra obtained in air ($p = 0.1$ MPa) for two electrodes alloys: a – CuW, b – CuZn. Exposure time – 0.7 ms

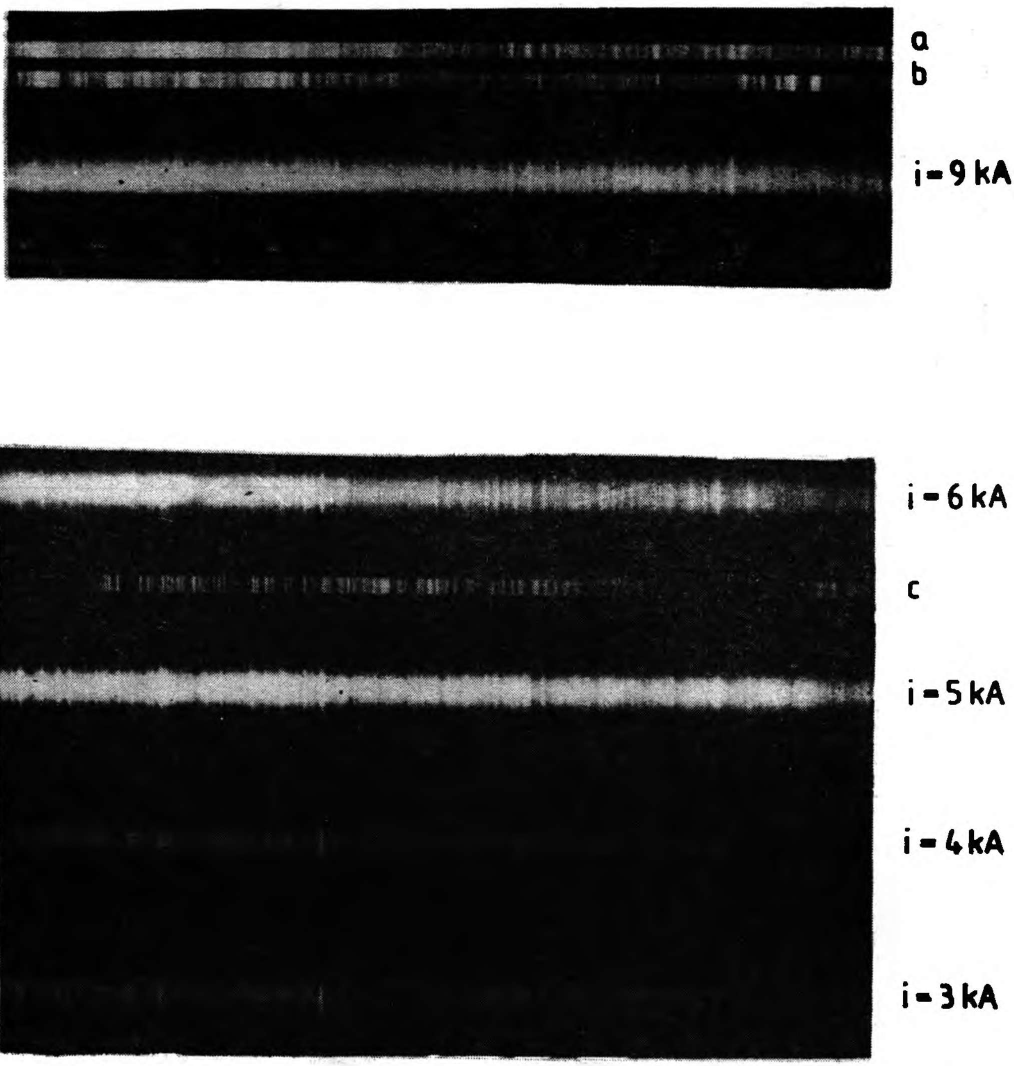


Fig. 23. Contact print of spectral plate with five-snapshot spectra of SAP in compressed air (p = 0.4 MPa) for different plasma current i (kA) with the same exposure time equal 0.7 ms (a, b, c — auxiliary emission spectra of short arc burning between CuW, Cu and Fe electrodes). The numbers describe a wavelength scale in hundreds Angström units

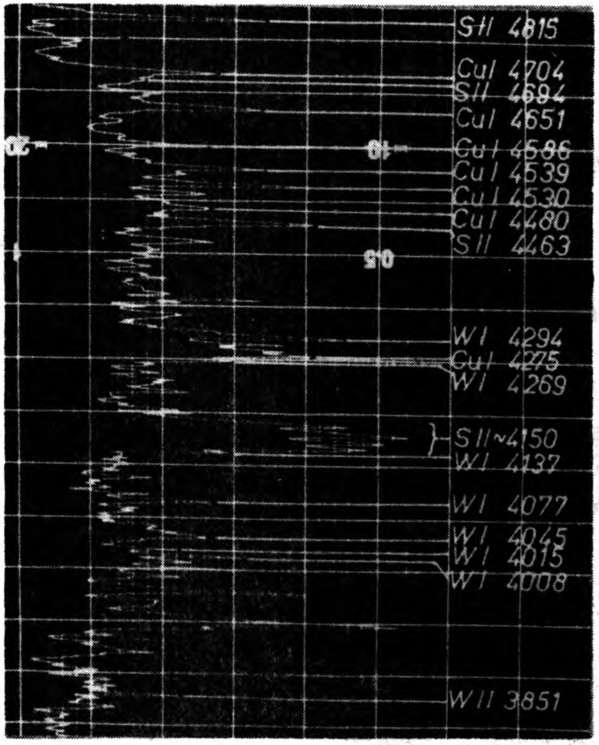


Fig. 24. Part of spectrogram of sulphurhexafluoride (SF_6) SAP emission spectrum consisting of the atomic lines of copper – Cu I, tungsten – W I, and ionic lines of sulphur – S II

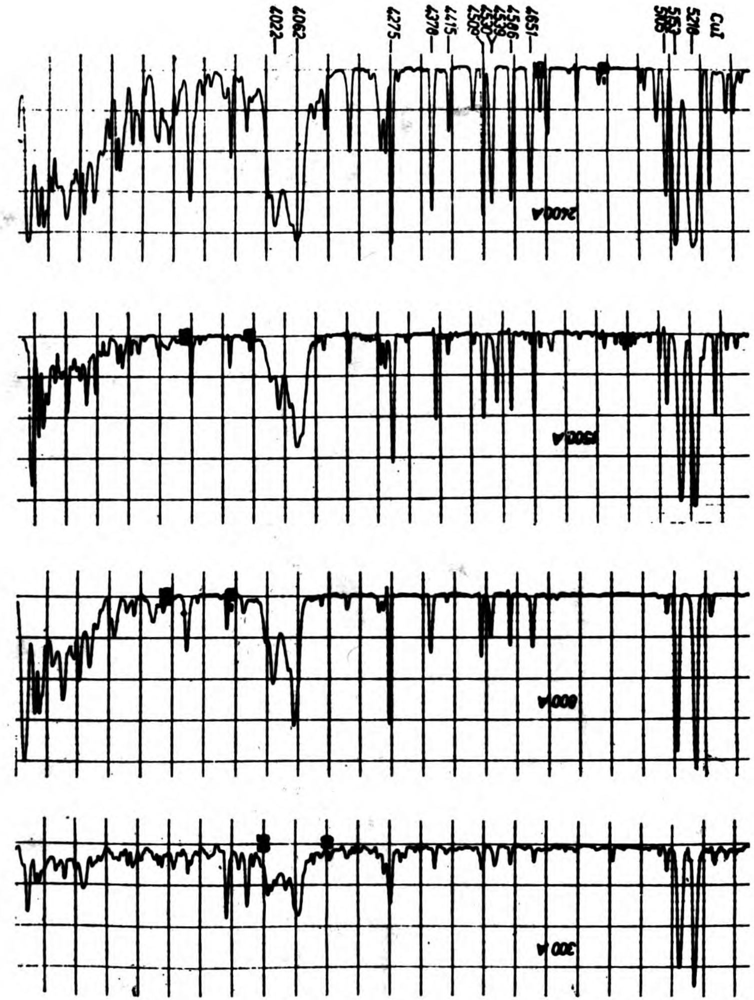


Fig. 25. Spectrograms of SAP spectra for different plasma current: $I =$ 300, 800, 1500 and 2400 A

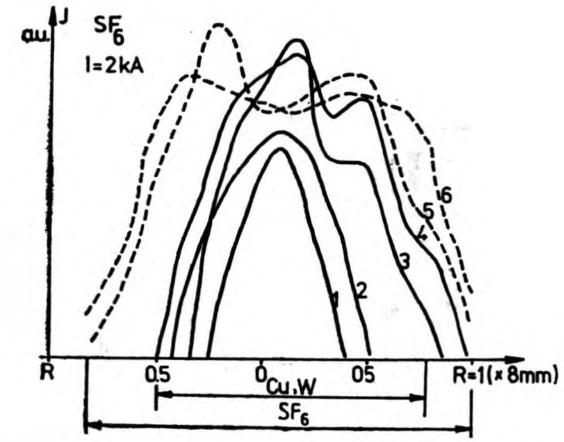


Fig. 26. Radial intensity distribution of spectral lines emitted by different species contributed to gas discharge in SF_6 with elkonite electrodes. 1: continuum ~ 4500 Å, 2: Cu I – 4486 Å, 3: W II – 3376 Å, 4: W II – 3851 Å, 5: S II – 4815 Å, 6: S II – 4153 Å

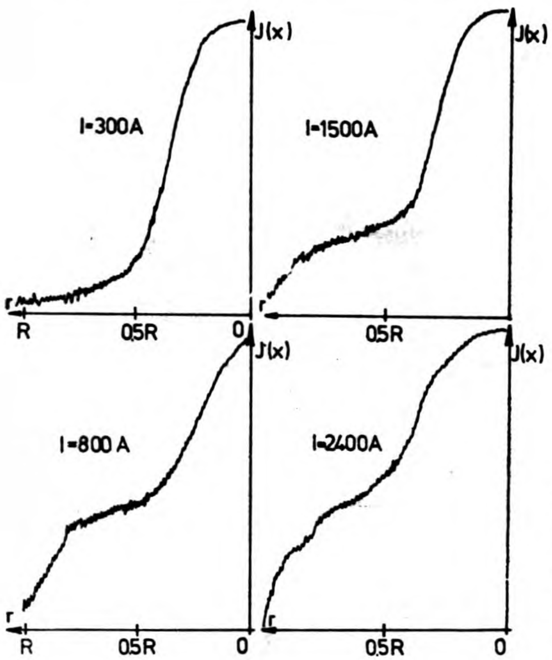


Fig. 27. Visualization of SAP boundary layer for different plasma current. The plots are derived from densitometric analysis of main spectral lines in radial direction (R), $J(x)$ intensity of spectral line

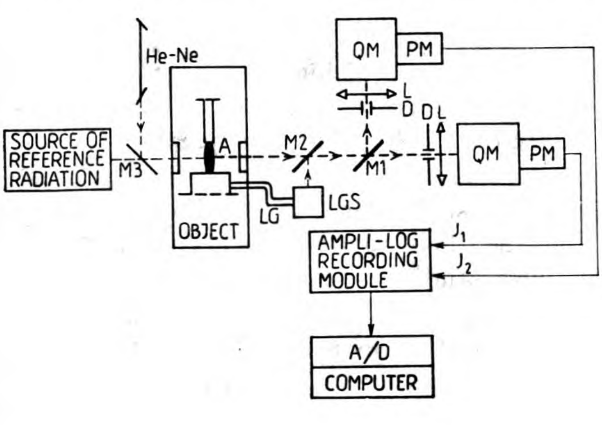


Fig. 28. Spectrometric recording system: A – arc, QM – quartz monochromators, PM – photomultipliers, M1 – half-transparent mirror, M2, M3 – auxiliary mirrors, He-Ne – laser lamp for positioning control, LG – light guide 2 m long, LGS – light guide stand, A/D – analog/digital converter

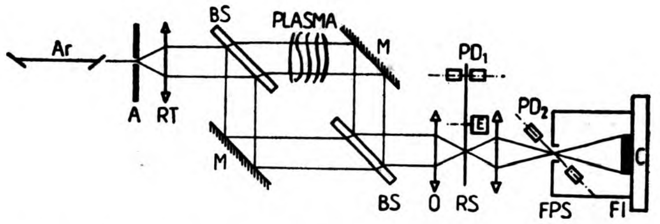


Fig. 29. Optical lay-out for Mach-Zehnder interferometric system: Ar — argon laser, A — aperture, RT — inversed telescope, BS — beam splitter, M — plane mirror, O — objective, RS — rotating disc shutter, PD_1, PD_2 — photodetectors for shutters control, FPS — focal plane shutter, FI — interference filter, E — driving motor, C — camera

3.2.6. Other measurements

Since the circuit-breakers operate most often with moving quenching gas it is a matter of the utmost importance for engineers to know the gas velocity. In our Institute a double-beam laser Doppler technique has been developed. At the beginning a digital Laser Doppler Anemometry processor has been constructed [19] for a system shown in Fig. 31. Its frequency band from 1.5 kHz to 15 MHz allows the measurement of gas velocity in the range of 0.03–300 m/sec.

Basic research for design of modern magnetic blast switching devices require, for practical applications, a detailed knowledge about the arc motion, in particular, about the mechanisms governing the motion of a transversely blown arc. This is because the current limiting effects, contact erosion, re-ignition and other phenomena are significantly dependent on the arc motion.

Since the high speed photography methods are restricted by rather rough determination of arc velocity, the optoelectronical position indicator yielding a discrete information about arc motion (position, velocity) is applied. Such devices shown in Fig. 32 consist of the set of transmission tubes coupled via observing window eight light guides connected with common cathode of photomultiplier.

A use of special tape-recorder with frequency response up to 40 kHz enables the rotation velocity measurement up to few thousand meters per second.

The electrode erosion processes are studied with the help of different techniques:

— solid particle pulling is observed by means of high speed photography (see, e.g., Fig. 9a) or static photography which revealed a considerable relevance giving intense traces (Fig. 33) of emitting solid-liquid particles teared out from the surface of upstream electrode,

— changes in plasma chemical composition due to metallic impurities originated from electrodes are detected with the help of spectrographic analysis,

— quenching-gas degeneration is also studied by employing the infrared spectrophotometer,

— to study the conditions of contacts surfaces a TV microscope set-up is usually applied here (see exemplary prints shown in Fig. 34).

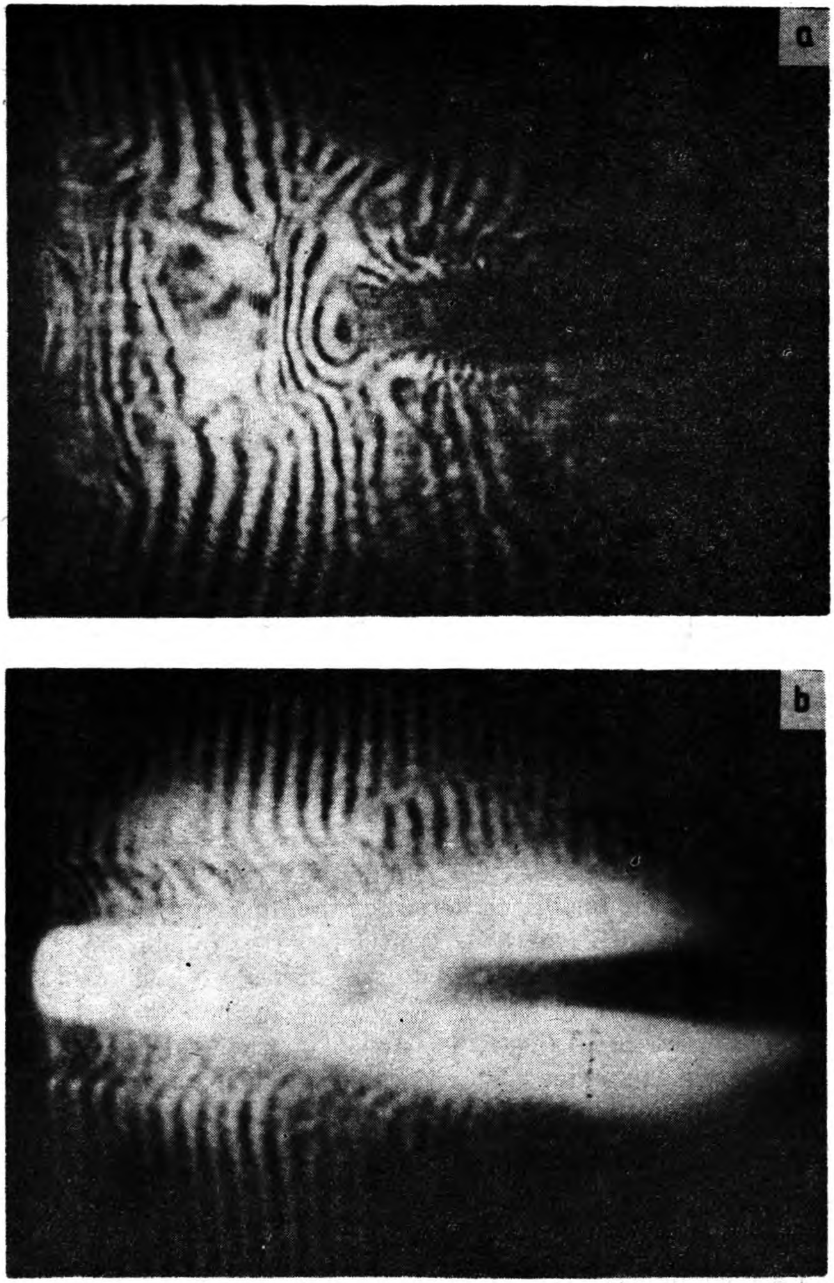


Fig. 30. Interferograms of axially blown switching arc plasma: a – cold gas flow, b – plasma core formation

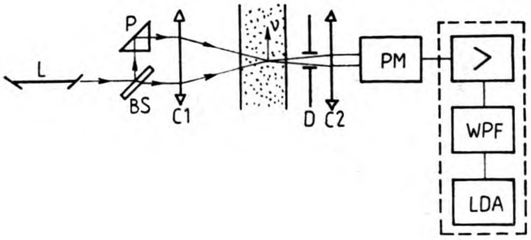


Fig. 31. Gas velocity measuring system: L — low power He-Ne laser, BS — beam splitter, PM — photomultiplier, > — preamplifier, WPF — wide pass filter, LDA — Laser Doppler Anemometry processor (digital frequency tracker), D — limiting aperture, C_1, C_2 — focussing lenses, P — prism

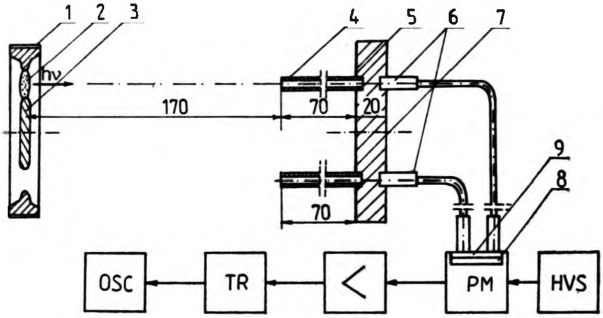


Fig. 32. Set-up for SAP rotation velocity measurement by means of optoelectronical position indicator: 1 — ring electrode, 2 — SAP, 3 — disc electrode, 4 — transmission light tubes, 5 — window's bluening surface, 6 — ight guides, 7 — observing quartz lwindow, 8 — photocathode of photomultiplier, 9 — mat screen (HVS — high voltage supply, PM — photomultiplier, < — ampli-log module, TR — tape-recorder, OSC — loop-oscillograph)

T4. Conclusions

The spectral diagnostics of different radiation sources have demonstrated its applicability to a detailed analysis of multi-parametric, emission structure of discharges of SAP, their intermolecular interactions, localization of the main region of PD in gap, and finally, to determination of many parameters, the latter being not possible by other methods. Considering the problem of partial discharges in terms of the behaviour of ionized gases on the surface of dielectric media or transparent solids, insulating liquids, it may be stated that it is an experimental tool with a great future, in particular, when connected with infrared spectroscopy. Such experiments carried out by help of Specord 71 IR Spectrometer have been initiated by the authors. From the practical point of view the above described methods made it possible to analyse different model arrangements and their usefulness as standard degradation sources for comparative studies of the resistance of different dielectrics to PD.

It should be underlined that in all the experiments in which the radiation from a cylindrical arc column is received by an arrangement which scans its projected area from side to side, the radiation received is integrated over all elements in line with the received beam, therefore, it is a function of the distance across the projected area, but not the true function of radius which is usually required. Whatever its form, it is necessary and possible to convert the observed profile into a radial variation by transformation based on Abel integral equation.

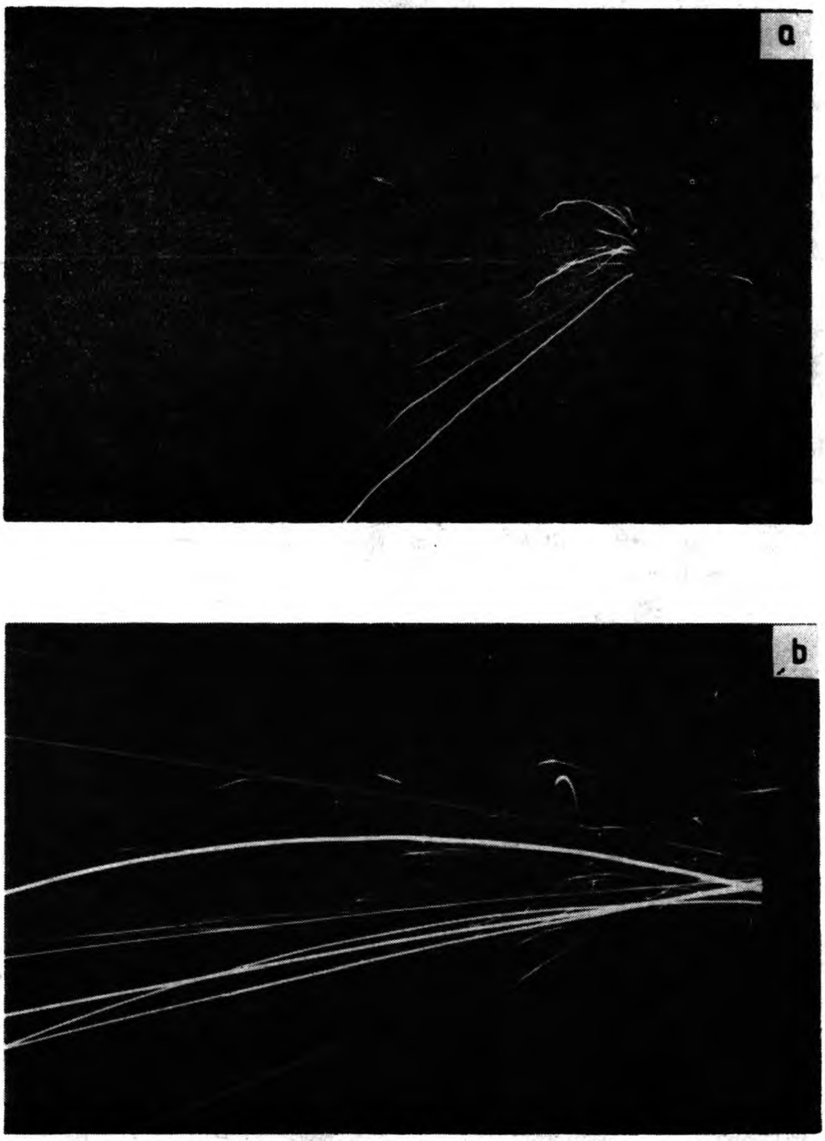


Fig. 33. Pictures of a long exposure time photography of electrodes erosion process in electrode configuration used in medium-voltage disconnector for two SAP current: a — I = 800 A, b — I = 2400 A

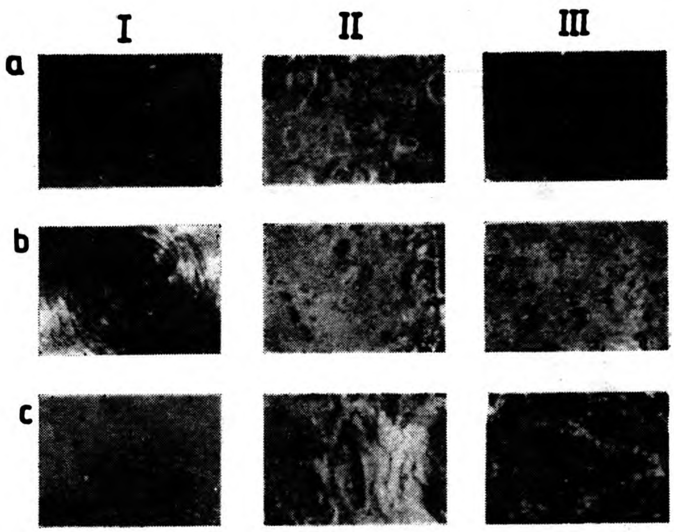


Fig. 34. Microscope prints of the end faces of different contacts: I — before test, II — after one test, III — after number of tests (a — elkonite, Cu W 80, b — brass CuZnPb, c — AgCdO)

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Применение оптических методов в инженерии высикох напряжений

В статье обсуждены разные оптические методы, которые помогают решать много научных и практических проблем инженерии высоких напряжений. Приведены примеры разных методов, применяемых для исследований частичных разрядов и коммутационной дуги в Институте Высоких Напряжений Варшавского Политехнического института. Доказана применяемость этих исследований.