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# CONTROL OF SELECTED VVER COMPONENTS LIFE TIME ŠKODA JS a.s. EXPERIENCE

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## ABSTRACT

Experience from the operation of nuclear power plants with type VVER reactors has shown that the life time management of a number of nuclear reactor components is technically as well as with respect to safety substantiated even at the time which exceeds their originally designed life time. To accept such solution it was necessary to develop and implement a number of programs based on which it was possible to evaluate the actual condition of monitored equipment. It is a condition allowing to adopt solution concerning the possibility of their further operation. Experience from the manufacture of 21 sets of reactor equipment for VVER 440 and 3 sets VVER 1000 has been gathered in ŚKODA JS a.s. which have been completed by experience from service activities performed at operated nuclear power plants. Analyses of manufacturing data and in-service inspection results completed by a lot of laboratory tests have become the basis for the development of selected VVER components life time management programs. The paper focuses on the life time management of those VVER components which ŠKODA JS a.s. has most experience with.

**KEYWORDS :** Control rod drive mechanism (CRDM), reactor pressure vessel (RPV), VVER reactors, life time management, lifeline of reference insulation system

## INTRODUCTION

A limiting component which so far in technical practice determines the entire NPP life time is a reactor pressure vessel (RPV). Its replacement has not been realized with respect to technical and financial demand factor of such an operation. However, it cannot be excluded that such a solution will be proposed in the future that will change the view at the technical life time of entire NPP. In addition to RPV there is a number of large components the replacement of which has been repeatedly performed, such as e.g. steam generators.

The situation concerning CRDM is somewhat different. While for the western type of nuclear reactors the CRDM life time was usually designed in compliance with the RPV life time, i.e. approx. 30 years, another, much more conservative approach was assumed for VVER reactors by design engineers. For VVER 440/V213, the original design life time of CRDM was specified only for 5 years, for VVER 1000/V320 the original design life time of CRDM was established for 10 years.

 

## 1. CRDM EVALUATION

At the beginning of 90s in the last century the operational experience at the oldest NPPs of type VVER 440/V213 (Loviisa) showed that the designed life time of CRDMs was specified with a too large margin. It was also proved by accelerated ageing tests of selected CRDM parts carried out at that time by some Russian organizations. It led CRDM manufactures to analyses of the actual operational condition and to the development of programs allowing to extend CRDM life time above the designed life time of 5 years.

ŠKODA JS having a leading position among CRDM manufacturers also started to occupy itself with the evaluation of CRDM actual condition. A research program was developed based on the following principles :

1. Analysis of operated CRDM design
2. Analysis of technical experience gathered during the manufacture of more than 1000 CRDMs.
3. Analysis of actual condition of CRDM structural parts (mechanical parts as well as electrical equipment) after reaching 5 years of operation, based on generally wide-spread test methodologies

The above principles were included in the inspection program which ŠKODA JS has step-by-step implemented at all NPPs to which it supplied CRDMs within the supply of nuclear reactors, i.e. to the Paks NPP in Hungary, Bohunice NPP in Slovakia and the Dukovany NPP in the Czech Republic.

Experience gained at individual NPPs during several years of the above program application proved that under certain conditions it would be possible to operate control rod drives even above the expected limit life time of 10 years. At the same time it proved that not only the operational time itself can significantly effect the actual condition of drives but also the specific operational conditions at individual NPPs. As an example we can mention the cracking of cooler outer body labyrinths caused by thermal-cyclic fatigue on several drives at the Loviisa NPP, or brittle cracking of position indicator sensor bearing rings which occurred mainly only at the Paks NPP and the cause of which was probably hydrogen embrittlement of bearing rings material. Another phenomenon which manifested itself after a longer time of operation was corrosion attack of those parts of electrical equipment which were made of electrotechnical ferritic steel and covered with a stainless steel layer. It related namely to position indicator magnetic shuts and electromotor rotors. First failures of this type were registered at the Bohunice and Rovno NPPs, later also at other NPPs.

Based on the analyses of measurement and inspection results at individual NPPs it was evident that

1. after modifications CRDM can be operated even after reaching 10 years of operation
2. it is necessary to complete so far applied inspection methodologies by new ones, namely for the evaluation of electrical equipment condition

Based on obtained experience the inspection program for NPPs has been innovated in ŠKODA JS. It has been completed by criteria for the evaluation of control rod drives condition with their operation exceeding 10 years. One of main changes consisted in completion of so called laboratory tests which samples taken from different parts of one CRDM, selected from a group of operated CRDMs, were subject to. It serves as a demonstration piece also presenting particularities of a long-term operation at a particular NPP. The scope of operational ageing effect on selected parts including weld joints on one hand, and the scope of effect on changes of base material properties of some exposed parts on the other hand are evaluated on material samples taken from various exposed parts of CRDM. Samples of winding taken from the electromotor and position indicator sensor are subject to evaluation of the extent of insulation system degradation, and residual life time of these systems is evaluated during additional laboratory tests simulating accelerated ageing.

When evaluating the actual condition of operated drives and possibilities of their further failure-free operation, the results of individual measurements and tests are analysed and compared with the results achieved during laboratory tests of samples from a selected drive at a particular NPP.

Inspection and measurement results obtained during the extension of drive life time at individual NPPs are stored in an integrated data base and are taken into account when making decisions on the possibility of further operation of particular drives at particular NPPs.

In parallel with works on programs focused on controlled ageing of operated CRDM VVER 440/V213 there were works performed in ŠKODA JS focused on the modernization of the CRDM structure. They were based on the assumption that the condition of components limiting the operational period of NPP, i.e. RPV, allows to extend the design life time above the originally considered 30 years, and the design of the existing generation of CRDMs does not allows such a long operation.

In parallel with works focused on CRDM VVER 440/V213 in ŠKODA JS, other works were focused on CRDM for reactors of type VVER 1000/V320. It allowed to utilize the experience gained so far during the modernization of structure of linear stepping drives designated for reactors of type VVER 1000 for CRDM VVER 440/V213 and vice versa. One of examples includes the application of stainless ferritic steel developed for magnetic circuits of CRDM VVER 1000 for position indicator sensor shunts and electromotor pole shoes of CRDM VVER 440. These were applied at the Paks NPP, Bohunice NPP, Dukovany NPP, Loviisa NPP and Rovno NPP at Ukraine.

Also other development results of modernized CRDM structure developed in ŠKODA JS have been gradually supplied as spare parts for operated CRDM to the above NPPs. As an example we can present new structure design of electromotor rotors, cooler body labyrinths, etc. This fact has been favourably reflected in the possibility to further extend the operational life time of the existing CRDM.

*Fig. 1.1 MKM-3 moment measuring device*

The use of newly developed fixtures for operating CRDMs during refueling outages is an integral part of complex approach to the solution of issues connected with the operation of CRDM at NPP. One of the targets is to provide for dismantle-free diagnostics of selected CRDM components condition (e.g. MKM-3 moment measuring device).

 

Experience from the operation of individual NPPs have shown that the use of nickel sealing rings in flange joints of the nuclear reactor upper block, as well as in CRDM joints, leads to gradual degradation of sealing surfaces namely due to plastic deformation and subsequent rise of microcracks. ŠKODA JS has developed its own structure of expanded graphite sealing rings for all types of flange joints in the upper block of VVER 440/V213 and VVER 1000/V320. The application of them allows to reduce the flange joint stress almost to a half and thus it substantially contributes to the extension of their life time.

| | Original | New recomendation |
|---|---|---|
| | Ni sealing | Graphite sealing |
| $M_k$ [Nm] | 1638 | 460 |
| $F_0$ [N] | 1128150 | 573000 |
| $\Delta l$ [mm] | 0,295 ±0.01 | 0,13 +0.01 |

*Table 1.1 VVER 440 CRDM flange joint*

The change of parameters for the tensioning of joints with expanded graphite sealing rings required new fixtures – tensioners, which have also been developed by ŠKODA JS.

*Fig. 1.2 VVER 440 Tightening Unit*

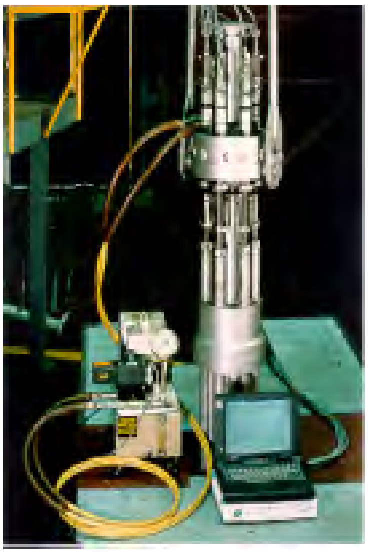

*Fig. 1.3 VVER 1000 Tightening Unit*

## 2. EVALUATION OF CRDM ELECTRICAL EQUIPMENT INSULATION SYSTEMS

If we go back to the issue of evaluation of CRDM electrical equipment insulation systems condition which operate in extreme operational conditions, we have to state that it is rather a complicated complex problem. Joint effect of temperature of ionizing radiation complicates the evaluation of the ageing process of NPP equipment insulation systems. The resulting IS resistance against operational stresses depends on material parameters selected by the manufacturer for a given application. The result is specific for every selected combination of materials. In order to assess IS technical parameters, it is necessary to determine dependences of the change of their properties during operation for the period of designed life time, or at the end of this period respectively. For this purpose it is possible to use the IEC recommendation.

With respect to the fact that the insulation system has a complicated physical structure and the operational stress effects its structure, we will mention only some aspects we considered during the monitoring of changes of its properties during operation .

Laboratory tests proved that it is the temperature which has substantially higher effect for the level of reached temperatures and radiation stresses in CRDM insulation systems.

The designed life time of CRDMs for reactors of type VVER 1000 is 30 years at an operating temperature of 300°C. The resulting resistance of the insulation system (IS) under such operational stress depends namely on parameters of used materials . As there were no data available from the manufacturers concerning long-term operation of proposed materials in specified extreme conditions, it was necessary to verify the properties experimentally by accelerated tests. With respect to the fact that the operational conditions include such levels of IS stresses for which we do not know ageing mechanisms and physical regularities of accelerated ageing, for the long-term tests we used the following certain assumptions.

The tests of long-term temperature resistance are based on reaction kinetics patterns. If one type of unimolecular reaction, pseudomolecular reaction resp., is the control reaction of temperature ageing in a certain interval, according to Arrheniov´s law or Büssing´s theorem there is a relation between the temperature and the concentration of materials entering the reaction in the course of time. However, more control reactions with different activation energies can proceed in a given temperature interval. They can have different temperature dependences of reactions speed. Such a case may occur when in the lower part of the time interval there is a dominant reaction with lower temperature dependence and in the upper part there is a reaction with higher temperature dependence of speed. The above described effect will manifest itself in dependence of time logarithm on reciprocal value of absolute temperature, by deflection from assumed linear dependence.

If we identify the state defined by a certain concentration of materials with the insulation state defined by the size of some physical property which changes in a monotonous way with progressing aging, then it is possible to find aging regularities of a given IS. If we designate the above defined state as the limiting state and corresponding to it physical property size as the end point, we will obtain a so called lifeline. It is a function of temperature and time needed to reach the end point. Based on experience, the lifeline position and incline of a large part of known organic electrical insulation materials can be roughly approximated. Where this is not possible, which is also in this case ( lack of knowledge about reaction kinetics of insulations in a closed sensor filled with helium), it is first necessary to define approximate position and then the incline of the lifeline. The position could be determined by modeling the conditions – temperature and time of ageing. After finding the position further test procedures corresponded to a standardized one according to the IEC.

Monitored during the IS tests were winding effective resistance, inductivity, coil quality, capacity, equivalent parallel conductivity, loss factor, insulation resistance, polarization index, active power at increased frequency and breakdown voltage.

Criteria of end points were not defined at the beginning of test, they were determined based on the obtained time courses of monitored physical properties and dependence on ageing time. Changing physical properties were mutually correlated and that is how the end points criteria were determined.

Of all obtained lifelines established from the above mentioned monitored properties the line with the smallest slope was selected. When extrapolating lifelines to lower temperatures it led to shortest times at the required temperature resistance of 300°C. A straight-line parallel with this slope which is as it were a limit hypothetical lifeline of IS satisfying in addition an operation life time requirement was led through the point corresponding to the life time of 30 years. Described results are shown in Fig. 2.1.

Based on the obtained limit line position and based on the requirement for the duration of the whole test a verification test of insulation system against temperature and ionization stresses was carried out. The verification test parameters were chosen so that the test simulated higher temperature stress than needed to achieve hypothetical limit lifeline.

It was found through the verification test that owing to the stress chosen in this way no significant deterioration of verified IS properties occurred and at the same time a state which would jeopardize its functionally was not achieved. The test results were extrapolated to the life time of 30 years and proved that the technical parameters of used insulation system should satisfy the required lifetime at permanent temperature stress of 300°C.

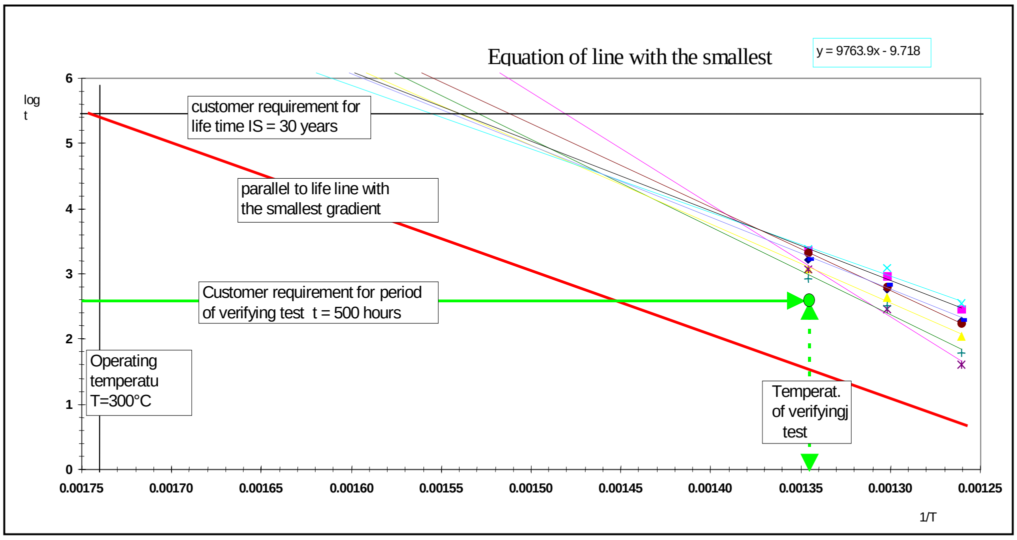


*Fig. 2.1: Lifeline of reference insulation system of position sensor coil- dependence of time logarithm on reversed value of absolute temperature*

We verified whether the insulation system keeps its expected parameters for the estimated life time of 30 years after 5 and 10 and 15 years of sensor operation at the VVER 1000 reactor. We present the results after 10 years. For this purpose the coils were removed from the sensor. They were subject to electrical nondestructive and destructive tests of the insulation system. Before removing the coils, samples of its internal gaseous atmosphere were taken for analysis from the position indicator. The purpose of the analysis was to find whether the internal atmosphere contains elements indicating desintegration products of insulation materials from sensor coils after operational stresses.

The analysis results were evaluated by comparison with the results of sensor filling gas analysis - helium, with sensor atmosphere samples which was not subject to operational stress, and with the analysis results of atmosphere from the container with the sensor coils which have low dielectric properties after temperature stress during a model test.

Hydrocarbons and carbon dioxide were identified in the samples of internal atmosphere after 10 years. It resulted from the analysis that operational stresses induce changes in the composition of the original helium atmosphere. From the results, we present identification of methane in Fig. 2.2 By the increase of its concentration, methane is a significant symptom of ageing. Its concentration in operational sensor was approx. 10-times higher (JuJe-1, JuJe-2, JuJe-3) in comparison with non-operational sensor (VS-1, VS-2, VS-3) , but approx. 8-10-times lower than in the atmosphere with aged insulation system from the model test (Degr.-1, Degr.-2, Degr.-3). Methane CH4 is very stable and after its development it does not react with present alkylated benzenes released from the insulation system at operational temperatures of 300°C. That is why its concentration will increase in the process of ageing. Therefore, it is a suitable indicator of such changes. However, according to methane the analysis result does not indicate a higher degree of insulation system age after 10 years.

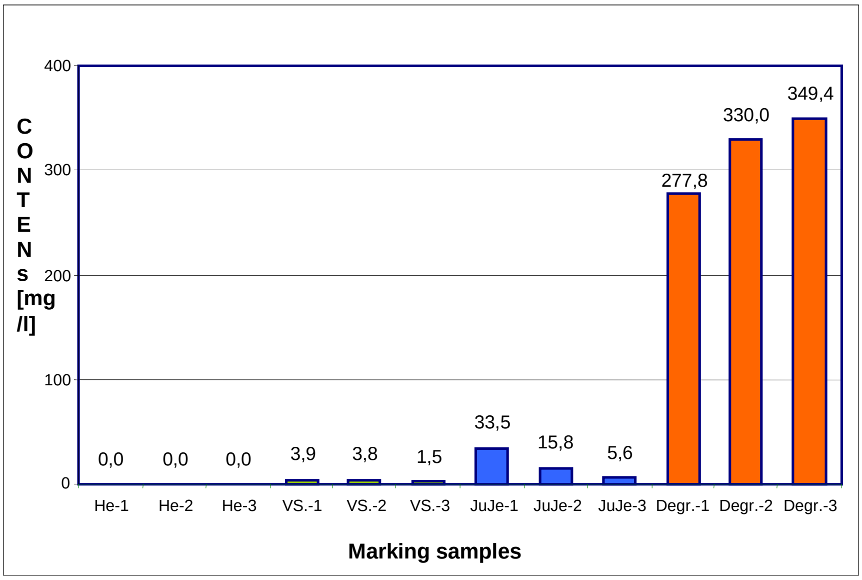


*Fig. 2.2: Capacity of metan in samples from pos. indicators UP1*

Subsequent electrical tests were performed to verify the condition of dielectric properties of sensor coils. It resulted from the measurement results that insulation resistances indicate unharmed measured insulations. During the measurements of capacities, loss factor resp., no values were recorded which would show evidence of a possible reduction of insulation. Measured values of inductivity and equivalent series resistance with two frequencies between outlets between which the coil is connected do not indicate any possible short-circuit of the coil or a short-circuit between individual coils outlets. No applied voltage breakdown occurred for the period of one minute during the coil test. In the end, tests of winding breakdown voltage against the coil frame were carried out.

The electrical measurements diagnosed satisfactory condition of the insulation system after 10 years of operation. Nevertheless, it was necessary to consider to what extent the degree of insulation system degradation corresponds to the assumed decrease of properties for the estimated life time of 30 years. For this purpose, results of standard dielectric property measurements before and after the model accelerated life test of the sensor insulation system were used. They are shown in Figures 2.3- 2.6. The value before the model test corresponds to non-operational sensor coil, the value after the model test of the sensor coil corresponds to 30-year operation. For information, the line indicating the trend of probable change of properties in time was shifted using the measured values. For comparison, the same figures show UP1 position sensor coil properties after 10 years of operation.

It results from the comparison of the trend of model system properties with sensor coils that effective resistance of operational coils increased (Fig.2.3.) It shows degradation. However, the level of degradation correlates with the trend of properties for the period of 10 years of operation.

The insulation resistance increased and after 10 years of operation did not reach the area of downward trend (Fig. 2.4). Neither the polarization index indicated any pronounced decrease of insulation system properties after 10 years of operation (Fig.2.5).

The test results of breakdown voltage between the winding and coil frame were the decisive property for the evaluation of dielectric properties condition (Fig.2.6). The test documents that after 10-year operation the decrease of insulation system dielectric properties is not higher that expected. The results show that the decrease of dielectric properties is slower than expected.

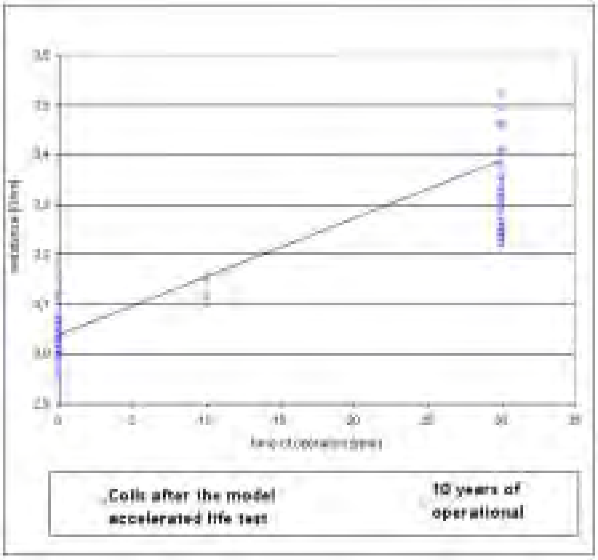


*Fig.2.3:Resistance of the winding sensor coil position UP1*

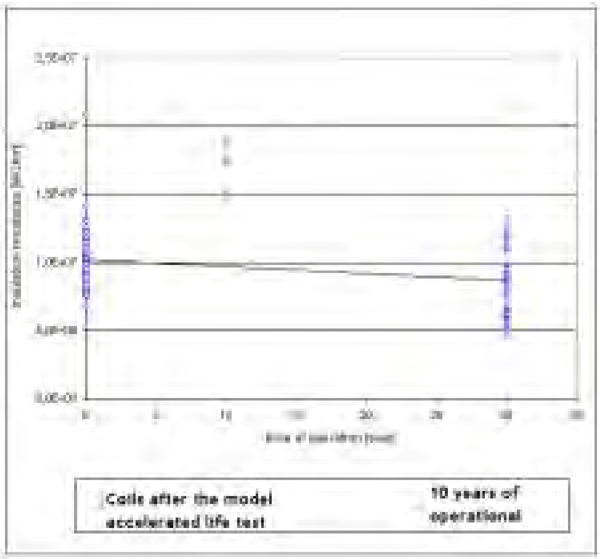


*Fig.2.4:Insulation resistance of the insulation systems winding of the sensor coil position UP1 to zhe frame coil*

 

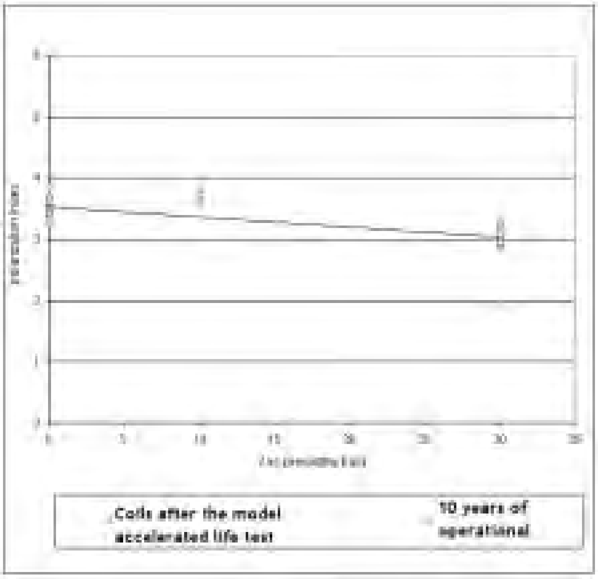


*Fig.2.5: Polarization index of the insulation systems of the sensor coil position UP1 to the frame coil*

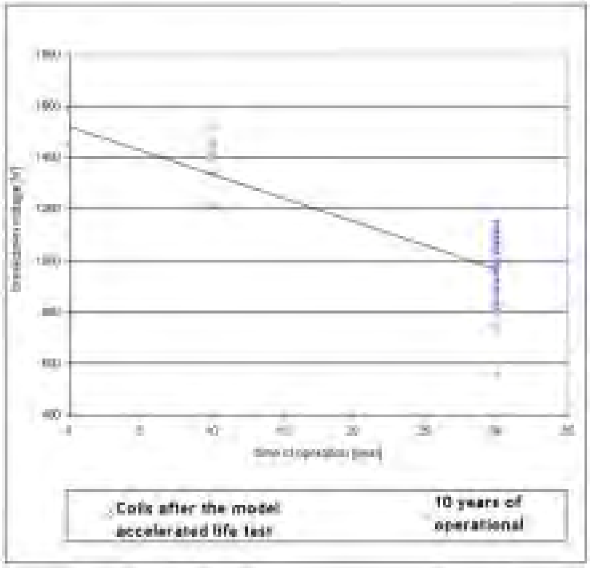


*Fig.2.6: Breakdown voltage of the insulation systems of the sensor position UP1 to the frame coil*

Currently, there are measurements in progress after 15 years of sensor UP1 operation. The results on complete sensors showed low aging of their insulation system also in the half of estimated 30-year life time. Measurements results and verification of the insulation system together with regular check measurements of operational sensors UP1 allowed to confirm prediction of their long-term reliability at nuclear power plants.

At the same time they prove that the insulation system composition is probably in correspondence with the requirements for extended life time of 30 years.

**Insulation system of motors RD42-4RV for VVER 440**

The original insulation systems of RD42-4RV motor winding for reactors of type VVER 440 were designated by the manufacturer for permanent temperature resistance of 180°C and for the operation in the reactor for the period of 5 years. A large part of them has already reached this operational life time. With the requirements of power plants for longer life time it is therefore needed to consider if their insulation system is capable to be in further and reliable operation. The insulation system of motors consists of polymeric materials whose susceptibility to the process of disintegration by operational stress is higher than that of inorganic components of the position indicator system for VVER 1000.

In connection with the above, we found during the diagnostics after the guaranteed life time that owing to the processes of ageing which manifest themselves by growth of cavities and finally by affecting the insulator compactness the insulation resistances can grow and provide thus incorrect information about the system condition. Therefore, we extended standard measurements by diagnostics of other quantities from the absorption part of the polarization process and of quantities from resorption polarization processes which take place in the motor insulation systems after disconnecting the voltage.

Within this extended diagnostics we measure time courses of absorption on one hand and resorption polarization process on the other hand in the time interval within 100s after connecting, disconnecting resp., direct voltage from the insulation system. Thus we can get a wider picture about ongoing processes needed for more correct assessment of system dielectric properties.

Connected with the absorption part of the polarization process are charging currents derived from which is the standard insulation resistance. The insulation resistance mainly characterizes the process of insulation netting. Then changes in conductivity of insulation surface layers induced by the effect of degradation products on the insulation system operated in a closed motor frame. The insulation resistence characterizes the condition of insulation system related to the applied insulation material and the technology of its processing.

Resorption part of the polarization spectrum with its charge released during the desintegration of polarizations and manifesting The decrease of its functional electrical parameters to minimum values is usually not the reason of the end of technical life of the motor insulation system operated a long time after the guaranteed life time. One of them includes e.g. the increase of gaseous products concentration. These can develop pressure in the stator internal space with a value exceeding mechanical resistance of the membrane separating motor from rotor. Its deformation causes non-functionality of the drive.

Another of the causes of possible life time end is connected with a long-term weight decrease of the system insulators. It causes mechanical desintegration of bounding compounds from surface insulators from impregnating varnish, bonding agents. It is accompanied by reducing the insulation and growing portion of air in insulation. It leads to mechanical destruction of the system.

itself as resorption current indicates, in comparison with the absorption part of the polarization spectrum, namely the increasing share of non-homogeneities in the insulation and diffusion of gaseous products into cavities in the system insulation. The charge itself originates at the boundary of material inhomogeneities and grows with progressing lamination of the system – by insulation reduction and growth of cavities.

Based on the diagnostics we can investigate whether e.g. the change of insulation resistance is caused by irreversible degradation of the material or it is reversible and caused by wetting or contamination or by elements of the internal atmosphere.

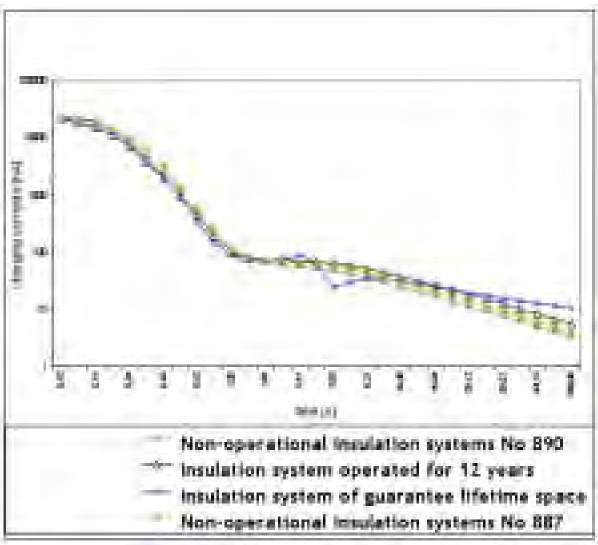


*Fig.2.7:Time courses of charging currents measurements results from insulation systems RD42-4RV*

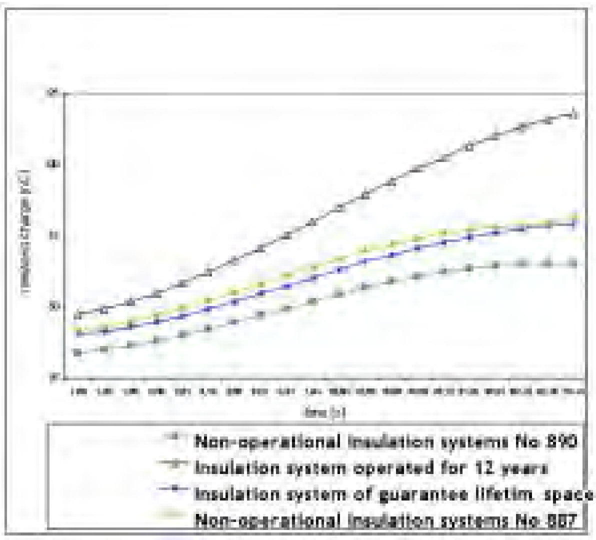


*Fig.2.8: Time courses of released charge measurements results from insulation systems RD42-4RV*

For illustration, Figures 2.7 and 2.8 show examples of charging currents time courses measurements results and a released charge from insulation systems.

An insulation system operated for 12 years has a time course of charging currents overlapping with non-operational insulation systems. It is comparable with them. The characteristic of a released charge at discharging polarization process is shifted to higher , i.e. more unfavourable values of charges, in comparison with non-operational systems. I.e. a released charge indicates decrease of dielectric properties after 12 years with respect to the initial state. The released charge indicates changes in the volume structure of the insulation system. Therefore it is a correct complement to the standard diagnostic values.

The results of time course measurements and derived from them diagnostic quantities are used first of all for the assessment of the operated motor insulation system condition with respect to the degree of ageing. For such purposes we have got a data base from measurements of motors operated in various times at nuclear power plants. Using it we can make up trends of probable changes in dielectric properties with their reliability intervals. From the point of intersections of property trends and reliability intervals with criterial properties measured on insulation systems of motors at the end of technical life time we can determine to what degree it is possible to extend the operation of insulation systems of the monitored set of motors at nuclear power plant. To go on assessing the properties of individual motors with respect to the monitored set of motors and to determine their probable residual life time and make a decision on further extension or reduction of the operational period.

**Related documentation:**


[01] Zdebor, J., New generation of control rod drive mechanisms and ŠKODA system of group and individual control for reactors of type VVER 1000, „Bezpečnost jaderné energie“(Nuclear energy safety), 4/2000.

[02] Zdebor, J.: Привод АРК реактора ВВЭР 440/В-213. Результаты контроля после 8-10 лет эксплуатации на Ровенской АЭС. Заключительный отчет ŠKODA Ae 9106/Dok/R, Plzeň, 1997

[03] Voldřich J. a kol: Control rod drive stress, V-213-Č reactor equipment set, Technical report, West-Bohemian University, PVtech, No.VZ 15/97, Plzeň, 1997

[04] IEC/TC 98: Revision of IEC 60505, Evaluation and qualification of electrical insulation systems, August 1997

[05] Pribulla, Ježek, Zdebor: Lifetime Test of Electroinsulated system used for High temperature operational loads, 2nd International symposium on safety and reliability systems of PWRs and VVERs, Brno Czech Republic, May 26-30, 1997.

[06] Pribulla E., Partial report on the second stage of UP1 position sensor insulation systems measurements after 15 years of operation at the South-Ukrainian NPP – processed measurement results of IS in 7.2004, Report 5301/2954/3/7/3-080624, IS Insulation systems, August 2004.


 