аэродинамической схемы поезда, созданию условий для минимизации расхода топливо-энергетических ресурсов и разрешению проблемы ресурсосбережения на железнодорожном транспорте проблемы железнодорожной аэродинамики не ограничиваются.

Влияние воздушной среды на поезд приводит в эксплуатации к отказам в работе различных подсистем подвижного состава, влияющим на безопасность движения (ходовых частей, тормозного, энергетического, электрического и другого оборудования, систем охлаждения, вентиляции, сигнализации, связи, телеметрии и т. п.); к возникновению дополнительных, неучтенных при проектировании, нагрузок, влияющих на прочность подвижного состава; утяжелению подвижного состава из-за осаждения на нем грязи, снега, льда и т. п.; загрязнению окружающей воздушной среды и внутреннего объема пассажирских и грузовых помещений вагонов.

Заключение

1. Снижать воздушное сопротивление можно за счет создания конструкций вагонов, которые бы создавали наименьшее сопротивление трения. Этого можно достигнуть за счет уменьшения поверхностей трения вагонов, улучшения качества их изготовления, а также аэродинамического перекрытия междувагонных промежутков.

2. Выбор схемы состава, аэродинамическая защита грузов на открытом подвижном составе, их размещение на вагоне, рациональная загрузка, придание вагонам выгодного состояния и т. д. дают широчайшие возможности для уменьшения влияния воздуха на поезд.

3. При создании подвижного состава XXI века необходимо проведение глубоких научных исследований с обязательным учетом воздействий на него воздушной среды.

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ANALYSIS OF THE INFLUENCE OF DESIGN FACTORS ON THE WINDING RELIABILITY OF HEATING ELECTROMECHANICAL TRANSDUCERS

We investigate the influence of the design factors of the capsulated windings of the heating electromechanical transducers such as the slot space factor and the length of the end stator coil on their reliability.

heating electromechanical transducer, winding, reliability, slot space factor, length of the end stator coil, turn and major insulation, temperature, vibration acceleration

Introduction

The investigation of winding failures of traditional electromechanical transducers shows that the estimation and prediction of their reliability can be based on the quantitative analysis of changing the properties of insulating materials under the action of the complex of external and internal breaking factors of the design and operation nature [1, 2]. The results of the analysis of the influence of the operation factors on the reliability of the heating electromechanical transducers (HEMTs) lead to the same conclusion. They also show that the temperature and the operating time have the determining meaning. The temperature and the operating time are actually linearly connected with the faultiness of the turn and major insulation [3]. The use of the capsulated stator windings in the HEMTs reduces considerably the influence of the vibration strains and humidity on the reliability indexes. This allows to achieve the influence of the design data on the reliability of the windings during the design stage taking the operational factors into account. First of all, we consider the variable design values such as the slot space factor ($K_з$) and the length of the end stator coil (l_s). These values determine the processes of the defect formation in the most stressed unit of the HEMT which is in the turn insulation of the capsulated stator.

1 Mathematical model

The analysis of the foreign and domestic literature shows that there is no approbation information on the qualitative and quantitative indexes of the reliability of the capsulated windings. Therefore, we use the method of an experimental design in order to construct a mathematical model of the defect formation in the turn and major insulation of the capsulated windings while changing their design parameters. We take the slot space factor, the length of the end stator coil and the wire diameter d as the input factors determining design features of the manufacture of windings. The performance criteria (the temperature of the winding and the level of vibration acceleration) have been chosen according to the purpose of the transducer and its operation mode.

To obtain the experimental data in order to calculate the factors of the mathematical model ½ of the replica of the composite rotatable second-order design for five factors have been realized, two of them (the temperature and the vibration acceleration) being operational. To obtain the response in the form of the time explicit function we vary the factors determining the dynamics of wear process of the electrical insulation and we estimate the rate of the wear process flowing by determining the response arguments in some successive points of time which gives the chance of obtaining and analyzing the results for each point of time and varying the experiment duration.

In the ageing process under the effect of the investigated factors we take the rate of the defects growth in the turn insulation H_B as the argument of the response in the design of the experiment. The rate of the defects growth in each point of the design of the experiment at the fixed levels of acting factors should be the value of the constant magnitude and it is determined by the following equation:

$$H_{Bj} = \frac{\lambda_{Bj} - \lambda_0}{\tau_j},$$

where λ_{Bj} is the faultiness of the turn insulation during the ageing process; λ_0 is the faultiness of the turn insulation at the beginning of the ageing process, τ is the ageing time.

The mathematical check of this supposition is made by Fisher's test [4]:

$$F = S^2_{\alpha g} / S^2_y,$$

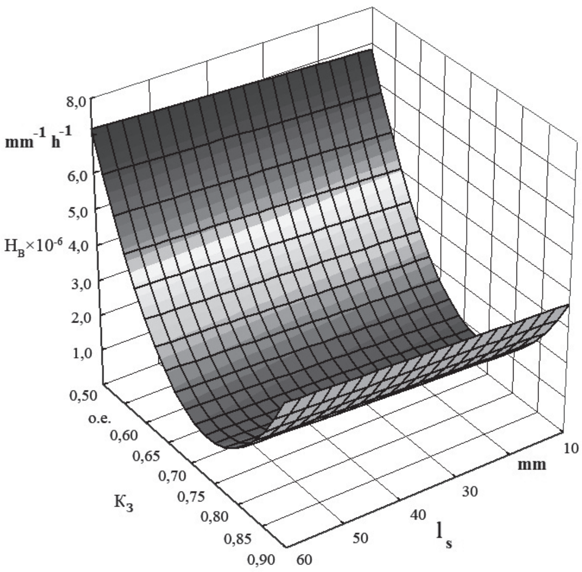
where $S^2_{\alpha g}$ is a variance, caused by the deviations of the rate of growth of faultiness calculated in each time point in the i^{th} experiment from the average value of the rate of the defect formation in this experiment; S^2_y is a variance caused by an error of the experiment.

2 Analysis of research results

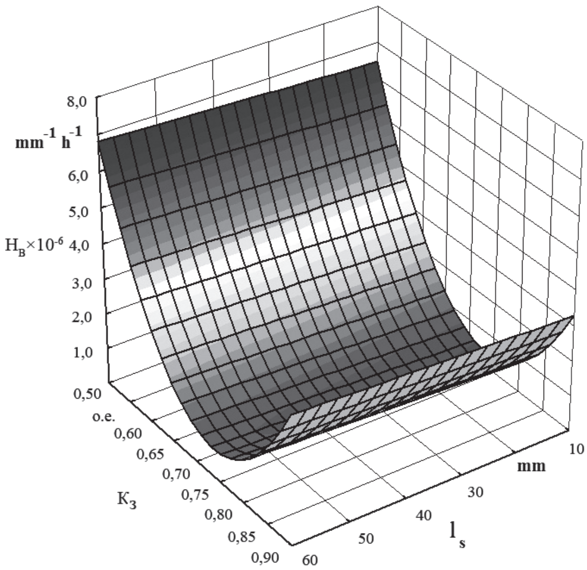
The comparison of the results of the variance analysis with the critical value of the F-equation ($F8/3 \geq 4{,}07$ at $\alpha = 0{,}05$) shows that the rate of the defect formation in the turn insulation at the fixed levels of factors also remains constant, which gives the chance to represent the response function in the suitable form for the practical usage and provides the accuracy of the description of the experimental results.

For describing the response surface we take the average value of the rate of defect formation $\bar{H}_B$ calculated by the results of the parallel experiments as the response argument. The visualization of the simulation results is shown in Figure.

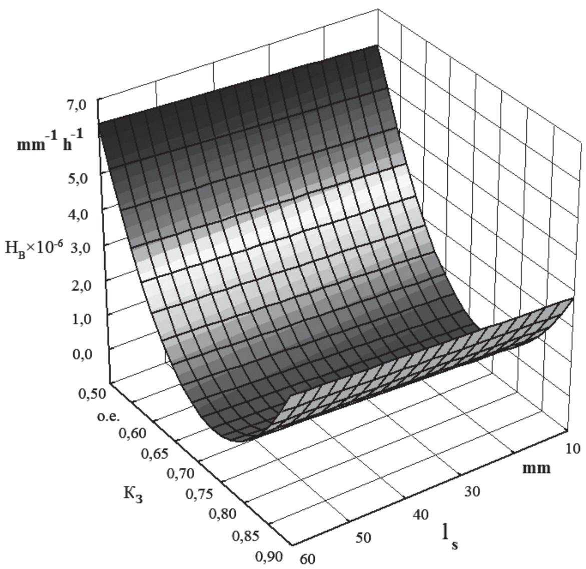
The analysis of dependences of the rate of the defects growth in the turn insulation on the investigated design features of the capsulated windings and the operation factors shows that all the chosen factors influence considerably on the rate of the growth of defects in the turn insulation at its ageing under the action of temperature. The increasing of the wire diameter leads to decreasing the number of the elementary



d = 0,25 мм



d = 0,75 мм



d = 1,25 мм

Dependence of the rate of growing faultiness of the turn insulation on the wire diameter, the slot space factor and the length of the end stator coil wires in the stator slot at the constant copper slot space factor. While manufacturing a winding made of wires with a small diameter we can see many crossings in the slot and end coil parts. These crossings lead to the destruction of the enamel insulation even under small forces in the places of a wire crossing under the influence of temperature or vibration. Increasing the wire diameter from 0,25 mm to 1,25 mm leads to decreasing the rate of the defects growth in the enamel insulation approximately by 14 %, i. e. from $1{,}478 \cdot 10^{-6}$ mm^{-1}h^{-1} to $1{,}298 \cdot 10^{-6}$ mm^{-1}h^{-1}.

The dependence of the rate of the growth of defects on the copper slot space factor has a nonlinear character with the clearly marked minimum in the range slightly overstated as compared to the recommended range for the traditional electromechanical transducers. The increasing of the copper slot space factor from 0,71 to 0,78 leads to increasing the rate of the defects growth from $1{,}388 \cdot 10^{-6}$ mm^{-1} h^{-1} to $1{,}931 \cdot 10^{-6}$ mm^{-1} h^{-1}, i. e. almost by 32 %. It is connected with the fact that the considerable thermo-mechanical forces act on the insulation of the capsulated winding when the number of wires is increased in the slot.

Decreasing the copper slot space factor from 0,71 up to 0,66 (by 5 %) leads to increasing the rate of the defects growth in the turn insulation from $1{,}388 \cdot 10^{-6}$ mm^{-1} h^{-1} up to $1{,}602 \cdot 10^{-6}$ mm^{-1} h^{-1}, i. e. by 15 %. It is evidently connected with the fact that the wires can move in the slots of the capsulated stator at small values of the copper slot space factor, which leads to the degradation of winding reliability indexes. When the winding is being capsulated the composite material can flow out from the slots without forming the insulation bridges between the wires. Thus, we receive an unsolid winding with bad cementation by the saturating composite material. The dependence of the rate of the defects growth on the copper slot space factor shows that the increasing of this factor over the range from 0,69 to 0,74 does not lead to the considerable changing of the rate of the defect growth (the changing is up to 3 %). Therefore, when manufacturing the capsulated stator windings of the HEMT the copper slot space factor can be increased by 5 % (to 0,74) which corresponds to the increasing of the usage of an active part of the HEMT by 3,75 % actually without increasing the faultiness of the turn insulation at the operation.

The increasing of the length of end coils of the capsulated winding causes a rather considerable influence on the rate of the defect growth in the turn insulation as well. When the action of the operation factors such as the temperature and mechanical vibrations, theoretically there can be concentrations of mechanical pressures in the winding insulation. These pressures influence on the wear rate of the insulation. While it is ageing the breaking of the insulation is progressing under the influence of vibration strains. The loosening of the fixing of the winding both in the slots and in the end coils stimulates breaking. The thermal and vibration ageing causes the sharp degradation of the insulation state at the input points of coils from the stator slots. The mechanical strains acting on the turn insulation at the input points of coils from the stator slots increase with increasing the length of the end coil. It causes the breaking of the insulation and appearance of defects. At changing the length of the end coils of the winding from 10 mm to 60 mm there can be seen the increasing of the rate of the defects growth in the turn insulation from $1{,}243 \cdot 10^{-6}$ mm^{-1} h^{-1} to $1{,}533 \cdot 10^{-6}$ mm^{-1} h^{-1}, i. e. by 23 %.

The quantitative estimation of the investigated design factors in the process of the defect formation in the turn insulation of the windings shows that the share of their contribution to the total value of the rate of the defect formation is: 10 % for the wire diameter; 30 % for the length of the end coil of the winding; 60 % for the slot space factor.

We can take the results of the investigation of influence of the design parameters of the capsulated windings on the wear of the turn insulation of the windings in the ageing process as the basis of the technological normative documents regulating requirements to the quality and to the design parameters of the capsulated windings, so we can use them while designing and manufacturing the heating electromechanical transducers.

Conclusion

1. The reliability indexes and the longevity of insulation of the capsulated windings of the HEMT in the operational process depend on the wear of insulation of the windings under the action of the system of the design factors.

2. The share contribution of the design factors to the total value of the rate of the defect formation is: 10 % for the wire diameter; 30 % for the length of the end coil of the winding; 60 % for the slot space factor.

3. We can use the engineering procedure of the experimental definition of the rates of the defect formation in the insulation for the estimation and calculation of the operational reliability and longevity of the capsulated windings of the HEMT. This procedure makes it possible to perform the comparative assessment of the quality of windings and estimate the efficiency of measures for improving the construction and technology of their manufacturing.

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