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ANALYSIS OF DESTRUCTION CAUSES OF RETAINING RING OF TURBOGENERATOR

Description of the destruction (emergency) of a retaining ring of a pre-series Turbogenerator of medium power is submitted in the scientific work. The following destructions were detected: rupture of the back part of the rotor retaining ring as per the generatrix, complete destruction of the external ring of the fan, blades, diffuser, tearing-off of the rotor coils, cutting of the rotor winding and its fastening parts, severe damage of the whole overhang part of the stator winding, complete destruction of the top row of the stator winding bars in the overhang part, rupture of the elementary conductors. The causes of destruction (emergency) are submitted: availability of cracks on the external surface of the rotor ring of Turbogenerator, nonconformity to the specifications on the plastic properties of the retaining rings metal, admission of the defects at manufacturing of the Turbogenerator rotor retaining ring at the manufacturer-plant (rough treatment of the retaining ring surface, availability of nicks and scratches, eight-fold heating of the retaining ring, fire in the generator). The design peculiarities of the rotor retaining ring of Turbogenerators. The causality analysis of the retaining ring damage was carried out. It is shown that the cause of the emergency can be a chain of events not related to each other and individually each leading to a failure or emergency. It is found that the events, the probability of which lies on the edges of the power-series distribution, the so-called "heavy tail" distributions shall become the most probable if they can cause maximum loss due to damage. One approach is considered in an attempt to answer the question: whether there are objective regularities in describing the consequences of major emergencies and catastrophes in the technosphere and in nature. Since the probability of a defect in the part shall be inherent for all stages of the service life cycle of the design (design working out and studying, technological preparation, manufacturing of the part, testing for compliance with the technical parameters, assembly, testing of the general design), then for the most unfavorable event with "heavy tails" the decisive factor shall be the human factor, to predict the change and behavior of which is almost impossible. The sequence of execution of technological operations for the elimination of rejection is established.

Keywords: *turbogenerator, emergency, fault, fault criteria, retaining ring*

Introduction

In accordance with the Energetics Strategy of Ukraine for the period up to 2035 the electric power consumption in Ukraine shall achieve 395.1 bln. kW·hours at its generation by all kinds of power plants shall be of 420.1 bln. kW·hours (base case scenario). At that the thermal power plants shall generate of 180.4 bln. kW·hours of electric power, that demand installation of generation power of 46.4 mln. kW, or 52.43% from the gross power plant output, which comprises of 88.5 mln. kW [1].

Therefore, covering the growing requirements shall be with existing power units, due to over-planned loads. So, there are possible consequences associated with decrease in the resource of the existing generating equipment.

Statement of Task

Analyze the cause-effect relationships of the occurrence of the defects and damage of Turbogenerators at all stages of the life cycle. Assess the possibility of a long-term operation ensuring of the Turbogenerator set throughout the life cycle, by optimizing the turbogenerator system modeling [2-6].

1. Turbogenerator Design

Since 1946, the first Turbogenerator with indirect hydrogen cooling rated 100 MW was manufactured at the territory of the CIS-States. Six years later a Turbogenerator rated 150 MW was manufactured, becoming the largest in Europe. Application of hydrogen, which has 14 times less density and 44% higher heat transfer coefficient than air, let significantly increase the unit capacity and the efficiency of those Turbogenerators.

At unit capacity of Turbogenerators rated 150 MW the possibilities of indirect hydrogen cooling were practically exhausted. Subsequently, designs of Turbogenerators were developed where hydrogen was directly fed to the copper of the rotor winding in special copper channels of the winding itself. This allowed in another couple of years to manufacture Turbogenerator rated 200 MW.

In Fig. 1 the design of a composite shroud ring is presented. Where 1 – the bandage ring; 2 – centering ring; 3 – the fan; 4 – elastic centering ring [7].

The rotor of Turbogenerator has already become single piece forging. The retaining rings are shrink-fitted onto the elastic rings, so that the calculated and actual stresses in the retaining rings lie within the permissible stress relatively to the yield limit. The design peculiarity was that the retaining ring consists of two halves connected by a lock. Between the centering ring and the insulation disc separating the winding of the rotor from the centering ring, aluminum spacers are forced in. From axial shifts the retaining ring is fixed on the centering ring with the end key. For the key pressing-off in the retaining ring there are a number of holes.

Due to the fact that given specimen was the first in its series and then that generator a number of issues of a technological nature were considered. The winding of the rotor was rewound several times. Due to a fire in the winding and iron of the stator, the core was subjected to restacking-up and rewinding. The rotor was tested for 2 times at speed at n = 3600 rpm. Heating of the retaining rings before they were placed on the rotor was carried out in a furnace with temperature controlled by a thermocouple. In order to remove the rings from the rotor heating was carried out by autogenous burners. The retaining rings were machined on the turning-centering machine, clamped into ordinary cams, at that the external surface being machined prior to being fitted on the rotor with an allowance of approximately 1 mm per a side, and then the rings were finally thoroughly machined on the rotor. When the material of the ruptured retaining ring was broken, one of the four samples could not withstand the elongation test.

2. Turbogenerator Emergency

One autumn morning the power unit with pre-series Turbogenerator was started up and synchronized with the network in an hour. The hydrogen pressure was 2 atm (gauge). During the start-up, regular measurements of vibration were made, which were practically within the limits of the norm. Further, a strong blow was heard from the turbine in the generator housing. The generator was automatically disconnected from the mains by longitudinal differential protection, operating in 0.06 sec after the occurrence of emergency damages. The run out of the Turbogenerator was 38 minutes. The pressure of the water conduit in the generator did not decrease. The generator had no external damages. After removing of the end shields of the generator from the turbine end the following was found.

The rear part of the rotor band was torn along the generatrix and laid on the lower half of the stator winding overhangs. By one side of the ruptured retaining ring rested on the inner ring of the fan, while the other one rested freely on the inner winding of the stator. The outer fan ring, its blades, and the diffuser were completely destroyed. The overhangs of the rotor coils, located under the rear part of the retaining ring were torn off under action of centrifugal forces.

On the surface of the fracture of the retaining ring, two zones were marked, one of which, located at the locking part, had a salient crystalline fracture of 120 mm long.

The spall in its base (on the external surface of the ring) suffered a noticeable plastic deformation of the crushing.

On both sides from the damage point, on the external surface of the retaining ring at a distance of 220 mm from the locking part, four tortuous cracks of 5-10 mm in length were revealed. Another surface crack with depth of 2.5 mm was found at a distance of 200-250 mm from the rapture point.

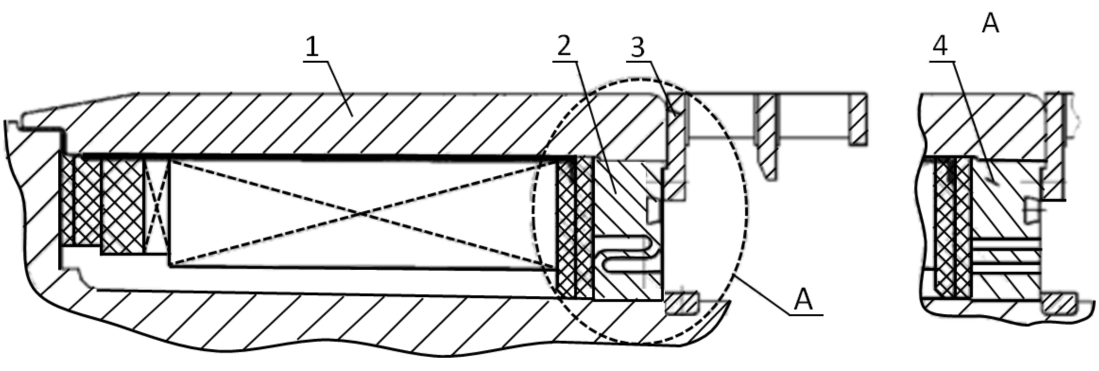

Fig. 1. The design of a composite shroud ring

Cut rotor winding and its fastening parts were thrown into the zone of the stator winding overhangs. Whole overhang part of the stator winding was badly damaged, bent and dented in the stator housing. The winding holders were deformed, their bolts were cut off. The top row of bars of the stator winding overhang part was completely destroyed, the elementary conductors were raptured. At the surface of the rotor body there were spalls of individual duralumin gas intakes probes of the rotor wedges.

In the stator winding overhangs there were some metal scraps, through out from the turbine end through the gap of between iron spaces. The binding of the rods in the lower half of the overhang parts was weakened and torn in places. The overhang parts of separate bars of the stator were shifted inside to the rotor in tangential direction.

From the turbine end in the left quarter of the stator winding overhangs after their partial cleaning, raptured cone hole was detected with the diameter of about 150 mm. The teeth layer had dents and nicks from impacts of metallic objects along the whole length of the bore.

At the rotor body surface a lot of gas intake probes of the rotor wedges had small spalls and at a half of undamaged bandage from the turbine end there were scratches and nicks.

At disassembly of the connecting coupling the bolts deformation, connecting the halves of the coupling, was detected. At three of them the maximum depth of dents achieved the value of about 1 mm. At the fit points of the teeth and noses of the retaining ring burns and melts were detected.

From the exciter end the fit points of 10 teeth and corresponding sections of the of the retaining ring nose were significantly melted. At seven teeth the traces of tarnish were detected, 13 teeth and corresponding sections of the retaining ring nose had no melts. Visible cracks were not detected. From the turbine end fit points of teeth and nose of the retaining ring had less degree of melting. Colours of tarnish were not also detected.

At the fit points of the noses of the retaining ring from the turbine end and exciter the traces of melts grinding and cleaning which took place at the stator and rotor damages at the factory stand of the manufacturer-plant were detected.

The same inspection the following faults at manufacture of retaining rings were detected. The groove to the centering key was bored after drilling and countersinking of pressing-out holes, which led to the forming of sharp edges.

The internal surface of the retaining rings had risks in transitions from the cylindrical belts to the outer surface. In general, a significant part of the surfaces had no required roughness according to the requirements of the existing design documentation.

3. Emergency Studying Results

The cause of the emergency of Turbogenerator was the rupture of the rotor retaining ring of Turbogenerator from the turbine end.

According to the opinion of L. Ya. Stanislavsky:

1. The ring rapture was as a result of cracks availability at the external surface of the ring.
2. The plastic properties of the retaining ring were not meeting the technical conditions.
3. At the manufacturer-plant the defects were made at manufacturing of indicated ring (rough surface machining of the ring, presence of nicks and scratches, eight-fold heating of the ring, fire in the generator).

4. Catastrophes with "Heavy Tails"

The issue of safety of the main generating equipment was the most deeply and in detail assessed for the NPP, since it is necessary to ensure a very high failure-free operation of the entire system [8].

Let us consider one of the approaches, in an attempt to answer the question: are there objective laws in describing of consequences of severe emergencies and catastrophes in the technosphere and nature.

In XIX century Karl Gauss found that probability of random variables distribution of different nature is described by the same mathematical dependence namely the so-called Gauss' distribution. The values of probability density of the Gauss' distribution show that large deviations from the mean values are rare and can be neglected. For example, for a normally distributed random variable, it is true that the values of such a random variable lie in the range of $[x + 3\sigma, x - 3\sigma]$ with at least 99.7% of confidence, where x is the mathematical expectation of a random variable, σ is root-mean-square deviation.

However, analysis of the statistical data of various catastrophic events shows that:

– major catastrophes occur more often than one might expect, based on the Gauss' distribution;

– some characteristics of natural catastrophes (including consequences) are well described by a power probability distribution, for which, unlike the Gauss' distribution, it is no longer possible to neglect events whose probability lies on the edges of the power distribution, the so-called distributions with "heavy tails" [9].

It can be assumed that such distributions are typical not only for damage from natural catastrophes, but also for damage from technogenic accidents: accidents at nuclear power plants; accidents of tankers and oil platforms; accidents at chemical enterprises, fires, destruction of oil pipelines, accidents of global computer networks, etc. Accidents at nuclear power plants, submarines, missile technology, aircrafts, have shown that it is not a question of random coincidence of failures, but of some common property of complex systems that begins to manifest if a certain critical level of complexity is exceeded. Despite the fact that technogenic risks are more manageable, due to the aging process of the main equipment and the reduction of the level of personnel training, we can expect an increase in the frequency of accidents and catastrophes at potentially hazardous facilities.

At the present time, it is known that many technogenic accidents and natural disasters are of a systemic nature namely a major catastrophic event is not due to an unfavorable combination of circumstances, but due to the inherent complex systems propensity to disastrous behavior. Some mathematical patterns of such catastrophes are described by power distribution of probability. Concrete processes leading to power distributions can be very diverse, depending on the relationship between the roles of these processes and the phenomena of self-organization.

In the technical literature, much attention is paid to the search for and definition of universal scenarios for the dangerous catastrophic behavior of the systems and objects of various origins (technosphere, natural elements). The most widespread phenomenon was the self-organized criticality used to study natural elements (floods, hurricanes, earthquakes, tornadoes, snow avalanches, e. t. c.); for studying of crises in the economy and other spheres of human activity; in the technosphere (accident and catastrophe in transport), in the chemical industry and other dangerous technologies. In complex objects that have several levels of organization, there is a place for both random processes and deterministic ones. In some states of the system, random effects do not lead to crisis phenomena; in others they can cause an emergency process namely a catastrophe. In some states, the system is completely predictable and has a large forecast horizon, while in others the forecast capabilities are small [10].

At establishing of technological operations sequence the following general considerations shall be followed [11]:

– first of all, it is necessary to machine the surfaces of parts, which are the main bases for further machining;

– then it is necessary to carry out machining of the surfaces from which the thickest layer of metal shall be removed, since defects of the blank (cavities, inclusions, cracks, e. t. c.) shall be easily detected;

– operations, in the performance of which there is a probability of rejection due to defects in the material or the complexity of the machining, shall be performed at the beginning of the process;

– further the sequence of operations is established depending on the required surface precision: the more precisely the surface shall be, the later it shall be machined, since the machining of each subsequent surface can cause distortion of the previously machined surface. This is due to the fact that the removal of each layer of metal from the surface of the part causes a redistribution of residual stresses, which leads to deformation of the part;

– the surfaces that shall be the cleanest are also machined last. This eliminates or reduces the possibility of damage of the finished surfaces. If such surfaces have been machined before and then other operations have been performed, then they shall be machined repeatedly for final finishing.

5. Service Life Cycle of the Item

Let us consider the service life of the part:

1. Design working and studying.
2. Technological preparation.
3. Manufacturing of the part.
4. Check to correspondence of technical parameters of points 1, 2.
5. Assembly.
6. Testing of general design.

For parts under action of mechanical loads, limiting factors shall be change in the geometry of the design, as well as the replacement of the material. In order to provide for the non-admissibility of the occurrence of the defects, it is necessary to create the possibility of adjusting the geometric dimensions of the part.

In order to accomplish the task, it is necessary that the technological operation preceding the finishing can provide the possibility of a dimension maneuver for reaching the required minimum dimension.

6. Human Factor

In the interview PROFESSOR EMERITUS ROBERT G. BEA POSITION Professor Emeritus, Department of Civil & Environmental Engineering Co-Founder, Center for Catastrophic Risk Management University of California Berkeley [12] said that, in the event of a number of emergency situations, a person can interpret actions and events in such a way that shall be most acceptable for successful completion of work. Therefore, in a situation where one has to make a decision for an ambiguous event, the decisive factor may be the specificity of the specific executor, and the criterion shall be the decision taken by the brain on the basis of events and factors not directly related to the existing situation.

A lot of work has been devoted to the work of the human brain and its behavior. This description was presented most fully by N. M. Amosov when studying the neural circuit method [13]. According to the author, the following works can be classified as the main ones.

I. M. Sechenov argued that the different level of activity of the neuron is the most important mechanism of interaction of models. The discovery of conditioned reflexes and conditioned connections made by I. P. Pavlov gave an explanation for learning and self-organization. The doctrine of the dominant of A. A. Ukhtomsky allows us to assume the mechanism for the prevalence of the main model over all the others. If we add to this the work on the reticular formation, then, taken together, they prompted the idea of central regulation of cortical activity namely the system of enhancement-inhibition and the mechanism of consciousness and subconsciousness [13].

Z. Freud accurately substantiated the great significance of the subconscious in the psychic life of a human. The experiments of J. Delgado and N. P. Bekhtereva with implanted electrodes showed how sensory centers control behavior, being sources of activity for cortical models [13].

Finally, the research of N. P. Bekhtereva and others, so-called "code of words" was discovered, that is, the existence of the models of speech words themselves, which, apparently, are imprinted in several or even many ensembles of neurons. One should also mention P. K. Anokhin, who proposed general principles for the management of physiological processes. A simple enumeration of the basic ideas of neurophysiology shows that the hypothesis about the algorithm of intelligence is only one of the possible variants of their arrangement into a single whole. This is done in order to try to apply the method of heuristic modeling to the study of thinking and behavior. If neurophysiology goes to the psyche "from below" through analysis, from the mechanisms of neurons and their ensembles, then cybernetic modeling goes "from above", by synthesis [13].

From the presented it is clear that to describe the actions of the performer in a critical situation to the present date can only be unlikely. The limiting fact for a person shall be the possibility of using normative and technical documentation at the reflex level.

According to Heisenberg's uncertainty principle: "The observed reality varies depending on the observer. So, the facts are inconstant variable."

Conclusions

In case of severe accidents, events shall develop according to the worst scenario, according to the theory of "heavy tails".

The limiting factor that helps to avoid an accident shall be such designing in which the strength reserves shall not be reduced below the minimum with minor operational and technological operations of the product. And the personnel and the design staff shall have knowledge not only about the features of the design itself, but also its manufacturing technology, assembly and operation characteristics for all stages of its service life cycle.

In order to ensure the reliability of the entire system, the calculations of the newly developed design shall be performed according to the previously used analytical techniques, where, at first sight, excessive mechanical and thermal margins were identified that determined the degree of uncertainty and uncertainty of the systems behavior.

For the parts where the strength margins are critical and the calculated stresses are at the upper end of the yield limits, the operation preceding the finish shall allow correction of the error at the time of final machining, in order to eliminate the human factor.

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АНАЛИЗ ПРИЧИН РАЗРУШЕНИЯ БАНДАЖНОГО КОЛЬЦА ТУРБОГЕНЕРАТОРА

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В работе представлено описание разрушения (аварии) бандажного кольца предсерийного турбогенератора средней мощности. Установлены следующие разрушения: разрыв тыльной части роторного бандажа по образующей, полное разрушение внешнего кольцо вентилятора, лопаток, диффузора, отрыв катушек ротора, срез обмотки ротора и деталей его крепления, сильное повреждение всей лобовой части обмотки статора, полное разрушение верхнего ряда стержней обмотки статора в лобовой части, разрыв элементарных проводников. Приведены причины, вызвавшие разрушения (аварию): наличие трещин на внешней поверхности кольца ротора турбогенератора, несоответствие техническим условиям пластических свойств метала бандажного кольца, допущение дефектов при производстве кольца ротора турбогенератора на заводе-изготовителе (грубая обработка поверхности кольца, наличие забоин и рисок, восьмикратный нагрев кольца, пожар в генераторе). Детально изучены особенности конструкции бандажных колец роторов турбогенераторов. Выполнен анализ причинно-следственных связей развития повреждения бандажного кольца. Показано, что причиной возникновения аварии может стать цепочка событий, не связанных между собой и по отдельности каждая не приводящая к отказу или аварии. Установлено, что события, вероятность которых лежит на краях степенного распределения, так называемые распределения с "тяжёлыми хвостами" станут наиболее вероятными в случае, если они могут принести максимальный ущерб. Рассмотрен один из подходов, в попытке ответить на вопрос: существуют ли объективные закономерности в описании последствий крупных аварий и катастроф в техносфере и в природе. Так как вероятность возникновения дефекта детали будет присуща для всех этапов жизненного цикла конструкции (конструкторская проработка, технологическая подготовка, производство детали, проверка на соответствие технических параметров, сборка, испытание общей конструкции), то для наиболее неблагоприятного события с «тяжёлым хвостом» решающим станет человеческий фактор, предсказать изменение и поведение которого практически невозможно. Установлена последовательность выполнения технологических операций для исключения брака.

Ключевые слова: турбогенератор, авария, отказ, критерии отказа, бандажное кольцо.

АНАЛІЗ ПРИЧИН РУЙНУВАННЯ БАНДАЖНОГО КІЛЬЦЯ ТУРБОГЕНЕРАТОРА

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У роботі представлено опис руйнування бандажного кільця передсерійного турбогенератора середній потужності. Детально вивчено особливості конструкції бандажних кілець роторів турбогенераторів. Виконано аналіз причинно-наслідкових зв'язків розвитку пошкодження бандажного кільця. Показано, що причиною виникнення аварії може стати ланцюжок подій не зв'язаних між собою і окремо кожна що не призводить до відмови або аварії. Встановлено, що події, ймовірність яких лежить на краях статечного розподілу, так звані розподіли з "важкими хвостами" стануть найбільш імовірними в разі, якщо вони можуть принести максимальний збиток. Розглянуто один з підходів в спробі відповісти на питання: чи існують об'єктивні закономірності в описі наслідків великих аварій і катастроф в техносфери і в природі. Так як ймовірність виникнення дефекту деталі буде притаманна для всіх етапів життєвого циклу конструкції (конструкторське опрацювання, технологічна підготовка, виробництво деталі, перевірка на відповідність технічних параметрів, складання, випробування загальної конструкції), то для найбільш несприятливої події з «важким хвостом» вирішальним стане людський фактор, передбачити зміну і поведінку якого практично неможливо. Встановлено послідовність виконання технологічних операцій для виключення браку.

Ключові слова: турбогенератор, аварія, відмова, критерії відмови, бандажне кільце.

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