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11th International Conference on Renewable Electrical Power Sources

PROCEEDINGS

Editor Dr Milica Vlahović

Belgrade, November 02-03, 2023

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on Renewable Electrical Power Sources

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FOREWORD

The conditions created by the development of technologies in which modern man lives have led to a complex and paradoxical effect: that by removing obstacles on the way to a more comfortable, simpler, faster and more efficient life and way of working, man also generates numerous misfortunes, attracting dark clouds of threats to the survival of the planet and humanity. The question that concerns and affects all of us - all people, all living beings, systems in which life takes place, large and small, strong and weak - boils down to the problem of the negative impact of man on the environment; this issue invites us to an urgent solution by looking at the causes, proposing solutions, evaluating them, changing approaches and ways of thinking, as well as drawing correct conclusions. Simply put, by adapting nature to one's own needs, man threatens and damages it. That is why, with the joint efforts of all of us, individuals, organizations and states, it is necessary to take all possible measures to immediately prevent the negative effects that are ahead of us.

The importance of renewable sources of electricity, which this international conference focuses on, is noticeable from two angles: the first - it is certain that fossil fuels as a resource will disappear and it is necessary to find alternative sources, the second - the use of renewable energy sources by its essence implies "clean" technology that significantly contributes to reducing CO_2 emissions and thus mitigating climate change and reducing pollution, while encouraging social and economic development in all spheres of life.

The 11th International Conference on Renewable Electrical Power Sources is organized by the Society for Renewable Electrical Power Sources (DOIEE) at SMEITS, with co-organizers: The Institute of Architecture and Urban & Spatial Planning of Serbia (IAUS) and the Chamber of Commerce and Industry of Serbia, with the support of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia.

The registered participants designed their papers according to the given conference topics:
- *Energy sources and energy storage;*
- *Energy efficiency in the context of use of renewable energy sources (RES);*
- *Environment, sustainability and policy;*
- *Applications and services.*

Eminent authors - scientists, teachers, experts in this field from fifteen different countries: Algeria, Belgium, Bosnia and Herzegovina, China, Croatia, Greece, Hungary, India, Portugal, Saudi Arabia, Serbia, Slovenia, Spain, the United Arab Emirates, and Ukraine, contributed to the conference through sixty-nine papers that were reviewed by the Scientific Committee of the Conference, and after the review process were accepted for presentation at the conference and for publication in the proceedings.

At the end of this short message and at the beginning of the proceedings I believe that it can be proudly said that scientists, researchers, policy makers and industry experts gathered in one place, in order to exchange experiences and knowledge with the aim of promoting scientific and professional ideas and results of research, technology improvement for the use of RES, promoting the rational use of electricity, affirming and proposing inventive solutions in the field of sustainable sources of electricity.

Belgrade, *Milica Vlahović*
November 2023

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METODE BEZ RAZARANJA I UNAPREĐENJE POUZDANOSTI RADA KULE ZA HLAĐENJE, KAO ASPEKT TEMATIZACIJE OBNOVLJIVIH IZVORA ENERGIJE

NON-DESTRUCTIVE METHODS AND IMPROVEMENT OF THE COOLING TOWER OPERATION RELIABILITY, AS AN ASPECT OF RENEWABLE ENERGY SOURCES THEMATIZATION

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Apstrakt. Kule za hlađenje koriste značajne količine vode, a sistem za hlađenje je često najefikasniji korisnik energije u zgradi tokom sezone hlađenja. Maksimiziranje energetske efikasnosti sistema za hlađenje može se značajno poboljšati optimizacijom čistoće površina za prenos toplote kule za hlađenje i površina za prenos toplote sistema za hlađenje izmenjivača toplote..Kule za hlađenje vode spadaju u grupu kontaktnih razmenjivača toplote, i sastavni su deo gotovo svakog procesnog postrojenja, čiji otkazi mogu dovesti do dugotrajnih zastoja i značajnih gubitaka materijala. Imajući u vidu ovu činjenicu, neophodno je na pouzdan način proveriti electromotor, ventilator i njegove komponente kako bi se obezbedio potreban kontinuitet procesa u odgovarajućem vremenskom periodu. Ranije metode provere delova ventilatora u skladu sa uputstvima proizvođača uključivale su samo vizuelnu proveru lopatica ventilatora i proveru momenta zatezanja lopatica za njihove držače. Pomenute metode su se pokazale neefikasnim i nedovoljnim sa stanovišta održavanja procesnih postrojenja tokom radnog veka, što je dovelo do kvara ventilatora i loma držača lopatica na mestu spoja sa lopaticom. Stoga su, za potrebe odgovarajućeg održavanja, primenjene konvencionalne nedestruktivne metode za procenu površinskih i zapreminskih defekata držača lopatica. Ova metodologija provere držača lopatica je detaljno prikazan u radu.

Ključne reči: *Razmenjivač toplote, kula za hlađenje vode, električni motor, održavanje, ventilatori*

Abstract. Cooling towers use significant amounts of water, and the cooling system is often the most efficient energy user in a building during the cooling season. Maximizing the energy efficiency of the cooling system can be significantly improved by optimizing the cleanliness of the tower heat transfer surfaces and the heat transfer surfaces of the heat exchanger cooling system. Cooling towers belong to the group of contact heat exchangers, and they are an integral part of almost every process plant, which failure can produce long-term downtime and significant material losses. Bearing in mind this fact, it is necessary to check electric motor, the fan and its components in a reliable way in order to ensure the required continuity of the process in the appropriate period of time. Previous methods of checking fan parts in accordance with the manufacturer's manuals *included only visual inspection of the fan blades and checking the tightening torque of the blades for their holders. The mentioned methods have proven ineffective and insufficient from the point of view of maintenance of process plants during working life, which has led to the fan's failure and the blade holder's breakage at the point of connection with the blade. Hence, for the needs of appropriate maintenance, the conventional non-destructive methods for the assessment of surface and volumetric defects of blade holders have been applied. This methodology for checking the blade holders has been presented in detail in the paper.*

Key words: *Heat exchanger, cooling tower, electric motor, maintaince, fan.*

1 Introduction

Cooling towers remove heat from the recirculating water used to cool the process fluid in process plants, chillers, air conditioners or equipment to the ambient air. Heat is irreversibly released into the environment from the cooling towers through evaporation. So, by design, cooling towers use significant amounts of water. Also, cooling towers provide cooling for air conditioning, manufacturing processes, or power generation by using water evaporation to transfer heat from the process or building to the atmosphere. Because of this, cooling towers use significant amounts of water, and the cooling system is often the most effective energy user in a building during the cooling season. Maximizing a cooling system's energy efficiency requires assessing the entire cooling system (cooling tower, chiller, heat exchangers, etc.). It can be significantly improved by maximizing the cleanliness of the tower's heat transfer surfaces (plastic fill) and the heat transfer surfaces of the heat exchanger cooling system. Also, this maximization can be achieved by the appropriate design of the demister and by stopping the water droplets from leaving with the flow of moist air. Otherwise, the cooling water system will require additional water supply to ensure the cooling tower's normal operation. Of course, this will produce additional water requirements for consumption, practically considered waste and will not be treated as a closed circulating fluid system. A 1000-ton cooling system with a 5% efficiency improvement can save over 90,000 kWh annually [1].

Cooling towers (water cooling towers) are an integral part of almost every process, thermal energy, oil and gas plant, and its failure of which requires the entire process or part of the process to be stopped in order not to sample large material losses due to the increased heat load of the rest of the process. They belong to the group of contact heat exchangers with contra current flows of fluid phases. The hot water is brought by means of a collection pipeline from the corresponding production process to the top of the tower of the cooling tower and from there, by means of a system of sprinklers, it is evenly sprayed over the plastic filling and moves vertically downwards while the moist ambient air is introduced at the bottom of the tower (immediately above the collection basin) and flows vertically upwards (Figure 1). The heat exchange between the mentioned fluids is carried out through the filling, which is built into the cooling tower with the aim of increasing of the heat transfer surface between the working fluids. A suitable drop separator (demister) is placed above the filling, which has the purpose of eliminating the drops carried by the air current (Figure 2) [2,3]. The flow of cold water is most often carried out by a system of pumps installed directly next to the collection basin, while the flow of moist air is ensured by an axial fan placed on top of the cooling tower in the corresponding hood. Taking into consideration that cooling towers are integral parts of almost every large process plant, it can be seen that up to now there are no adequate technical and legal regulations that can validly assess the required reliability of water cooling systems during the working life of process plants. Bearing in mind the aforementioned fact and the very goal of this lecture is to supplement and expand the existing requirements for the control of cooling towers with data obtained directly from real industrial conditions and problems arising during their working life, in order to avoid their potential failures on the one hand in the future, while on the other hand, use the above-mentioned information to ensure an adequate methodology for the maintenance of newly created plant assessments.

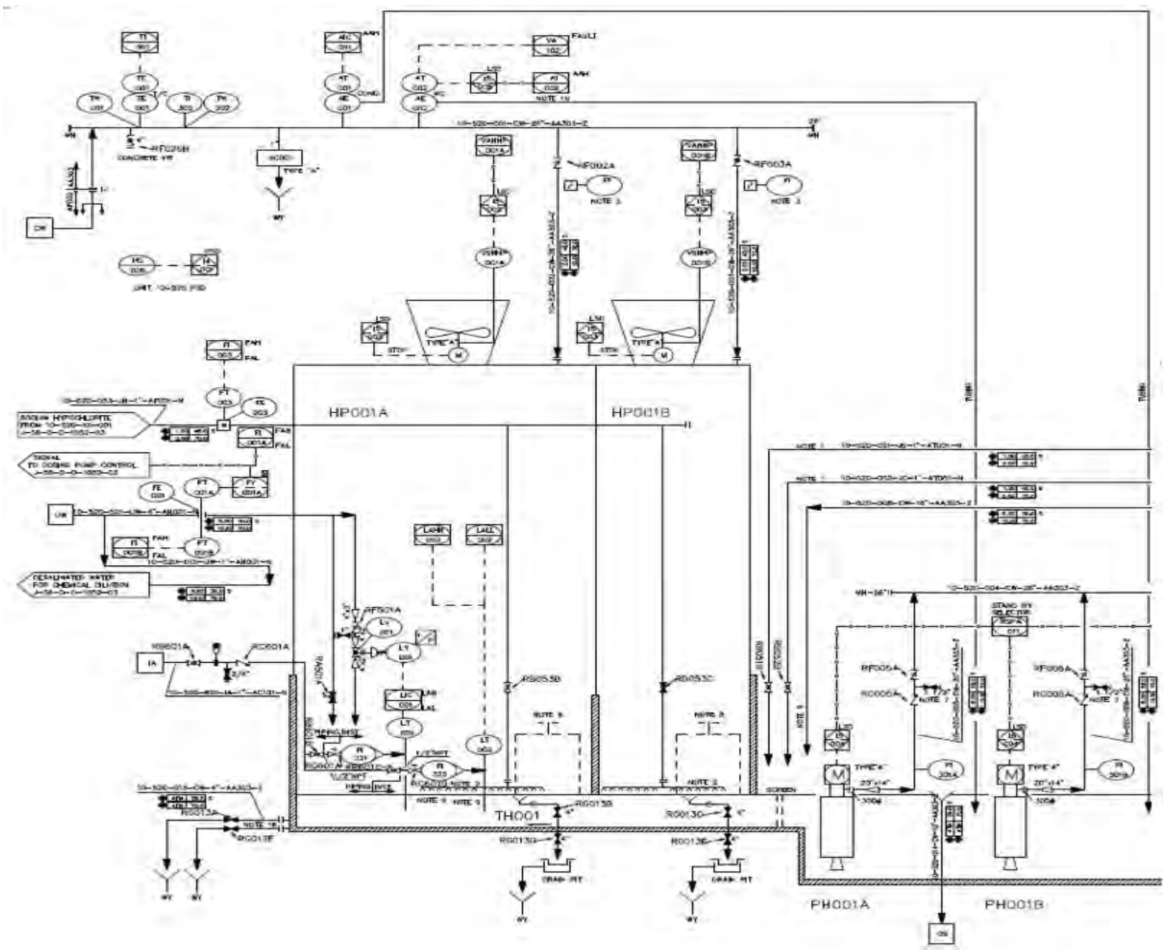

Figure 1 Process and instrumentation diagram of water cooling system of gas plants

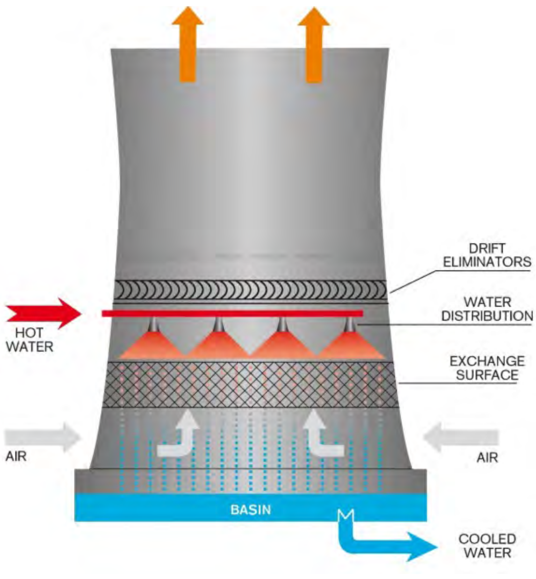

Figure 2 Display of the components of the water cooling tower

2 Analysis of current requirements related to maintaining the reliability of cooling towers

In engineering practice, the working life of a certain plant and individual devices (apparatus, machines, etc.) includes the following stages: development, dimensioning and production of technical documentation, apparatuses production, apparatuses functionality check after production, plant construction, i.e. device installation in a suitable complex system, functionality check after installation, maintenance, etc. For each of these phases, there is a developed technical regulation, as well as expert services that supervise them. It is characteristic that even in technically developed countries, device functionality checks are omitted or not carried out to a sufficient extent, although this provides an opportunity to correct observed errors and deficiencies, thus ensuring reliable operation and adequate capacity of the entire system. In the case of process apparatuses (which also include water cooling towers), the functionality check (operational correctness) is generally performed in three phases, which are listed in the lines below:

- check of test pressure, which determines the quality of the apparatus from the point of view of environmental hazards;
- checking the technological function of the device (for example, in the case of cooling towers, checking the thermal performance), that is determining the actual parameters of substance/heat exchange;
- checking of pressure drops of working mediums [2];

As can be seen from the above, the requirements for the reliable operation of the cooling tower refer only to checking of the test pressure in terms of the safety of the device for personnel and the surrounding environment, while requirements for assessing of reliability of the axial fan (which has been placed on the water cooling tower) and its components, from the point of view of safety and health at work, environmental hazards and long-term management of the production process are not covered by existing international standards and relevant technical and legal regulations. It should be noted here that the possible failure of the mentioned fan during work can cause serious injuries to the working staff and also great economic losses, especially in oil and gas plants, and sometimes long stoppages in the operation of entire plants, especially in summer time period. Such failures represent serious problems, especially when the aforementioned process plants (Upstream Oil & Gas plants) are located in remote, hard-to-reach and desert areas and when the repair of fan blade holders or the procurement and transport of appropriate spare parts is difficult.

The current standard ISO-16345:2014 also only refers to the evaluation of the thermal and current performance of cooling towers, while the reliability assessment model of the condition of axial fans is not included [4]. In the United States of America and South America, as well as in countries in Asia and Africa where oil and gas production and processing facilities are built in accordance with API standards, the CTI-A105(00) standard for assessing the condition of cooling towers is applied, and within this the standard only provides for a functional test in the sense of checking only the thermal and current performance of the cooling towers, while the assessment of the condition of the fan and the method of assessing the reliability of its component parts, especially the blade holders, are not taken into account [5]. Apart from the mentioned standards related to cooling towers, the manufacturer's instructions are often quite modest and, as a rule, include only visual and dimensional control of the blades [6-8]. Figure 3 shows an extract from the inspection and test plan of one of the manufacturers of cooling tower fans.

VENDOR: SPIG FOREIGN MARKETS S.p.A.	VENDOR'S JOB: F5022B02	PURCHASE ORDER: P-215A-003J-A

COMPONENT TESTED: 1 FAN	ITEM:	EQUIPMENT: 10-520-HP-001

Pos.	Q.C. Activity	Applicable documents.	Acceptance criteria reference.	Required Certificate	Involvement S	V	JV	TPI	C	AI	Report Nr.	Date	NCR Nr	Expected inspection week
1.1	Material certificate				3 (100%)	4	R							
1.2	Visual and dimensional inspection for Blade	V-215A-003J-A-107			1-3	1-4	H							8
1.3	Visual and dimensional inspection for Hub	V-215A-003J-A-107			1-3	1-4	H							
1.4	Blade static balancing with "Master Blade"				1-3 (100%)	1-4	H							
1.5	Hub static balancing (only for G hub)	V-215A-003J-A-107			1-3 (10%)	1-4	H							

Figure 3 Manufacturer's requirements for control of fan components during the service life

As seen in Figure 3, the control of the components of the fan includes only the visual and dimensional control of the hood and blades, while the control of the blade holders themselves, both in the area of its connection with the reducer on one side and on the other in the area of the connection with the blades, according to the manufacturer's requirements for control during the working life is not specified. It should be noted here that the previously mentioned blade holders need to be controlled during the lifetime of use, especially in critical areas due to the need to detect potential internal irregularities and above all fatigue cracks, in order to avoid potential fan explosions (failures) and thus stoppages in the operation of parts of the plant or of the entire plant. As previously stated, the most common methods of checking the correctness of fan parts so far included only visual control of the blades themselves and checking the tightening torque of the fan blades for the corresponding holders.

In addition to the mentioned visual method, dimensional control was also practiced in some cases, which included the adjustment of an adequate angle of inclination of the blades in relation to the reference axis, however, this type of adjustment mainly depended on the required thermal power during a certain working period. The main disadvantages of the previously mentioned methods are reflected in the fact that it is not possible to stop the cooling towers every 2-3 months to check the blades on the one hand because stoppages in the operation of a certain part of plant or stoppage of entire plant will produce huge economic losses, while on other hand, applying the mentioned method cannot successfully identify surface defects that are not visible to the naked eye, which include and fatigue cracks, as well as internal fatigue cracks. The mentioned defects (fatigue cracks) in critical places arise as a result of vibrations during many years of continuous work. It is necessary to mention that on two towers that were checked in the past only by visual and dimensional methods in accordance with the manufacturer's instructions, the failure of the blades holders have occurred. In the Figure below you can see the failure due to fatigue cracks at the point of connection of the blade to the corresponding holder. The fractures occurred around the threaded joints of the fan blade holders.

Figure 4 Broken blade at blade holder joint at threaded joints (upper holder split due to fatigue cracks)

Introducing conventional non-destructive methods for needs of blade holders assessments

Given that it was observed that the existing methodology cannot successfully describe the problems that occur during the operational life of the fan, the main goal of this paper was to find a suitable reliable methodology that can be used to evaluate the blades holders in the most efficient, reliable and cheapest way possible in every moment. The first step in establishing a new methodology for assessing the condition of blade holders was determining the critical points where fractures can occur and the possibility of their detection. The previously mentioned critical points have been established based on experience and on the basis of analysis of previous fan blade holder failures. As it was found in operational conditions, the most frequent failures of the blade holders occurred at the places of the threaded connections of the blade to the fan holder and at the place of the threaded connections of the blade holder to the fan reducer, so accordingly these points were adopted as critical points. Taking into account that irregularities can be surfaces (fatigue microcracks that occur on the surface) and volumetric irregularities (volumetric microcracks that occur inside the material) and the fact that the evaluation methodology should be efficient, reliable and economically affordable, solving this problem went in the direction of adoption adequate non-destructive methods.

Taking into consideration the fact that the majority of fan blade holders have been made from carbon steel or austenitic stainless steel, for the purposes of determining surface irregularities in carbon steels, dye penetrants and magnetic particles were adopted as an conventional method, while only dye penetrants were adopted for purpose of determining of surface irregularities in austenitic steels due to the impossibility of applying magnetic particles on them due to their poor magnetic properties. For the purposes of determining internal irregularities, the most effective and also the cheapest model is conventional ultrasound examination. In the application of conventional ultrasound, the use of normal probes and normal S-S was also adopted, while for a reliable calibration model it was proposed to calibrate the probe and corresponding ultrasound devices on stepped calibration wedges [9]. For the frequency level of ultrasound probes that can successfully enable a clear separation of received signals as well as their adequate analysis, frequencies of 4-5 MHz are adopted. Here, one must also bear in mind and theoretical knowledge of moving of ultrasonic waves, i.e. the transfer of waves from the probe to the material which is under examination.

The main limitation that occurs when applying this method is that with small values of the thicknesses of the material, coming to the appearance of duplication and excessive dispersion of ultrasonic signals, and hence adequate evaluation is not possible [10-12].

3 Fan blade holders evaluated in the plants by using conventional method

Figures 5-12 show the evaluation of fan blade holders according to a new methodology that includes the application of conventional non-destructive methods in critical areas of the blade holders. As previously mentioned, the most critical places on the blades holders are the areas around the bolt connections where the blade is attached to the blade holder and in the area of the threaded connections where the holder is connected to the fan reducer (central hole). The results of testing and assessing the condition of the fan blade holder according to the new methodology, has been successfully implemented for the second year in line in the in two oil and gas plants in desert areas. Here, it is necessary to mention that in the past (2016) in these plants there were major failures on two blade holders (dischargers flying off), in one case the blade broke off from the holder during operation in the area of the connection with the holder, while in another case the blade holder separated from the reducer fan. At that time, the evaluation method was based only on visual and dimensional control. Surface irregularities during the application of the new model at the moment of assessing the condition of the fan blade holder were not observed either in the area of the threaded joints in the blade-holder area or in the area of the fan holder-reducer. The assessment of volumetric irregularities using mentioned method was carried out using a conventional ultrasonic Gilardoni RDG 600 device with the defectoscopic effect of the back wall when the ultrasonic wave passes through the material in question [13].

Figure 5 Top blade holder with blades-Top view (critical places are marked with the numbers)

Figure 6 Critical places on the down holder for blades after spraying developer-evaluation of surface irregularity

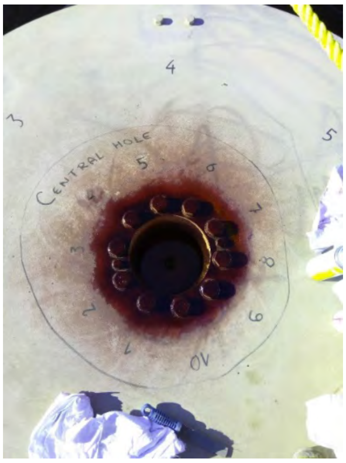

Figure 7 Critical places on the top holder for blades after spraying penetrant-evaluation of surface irregularity

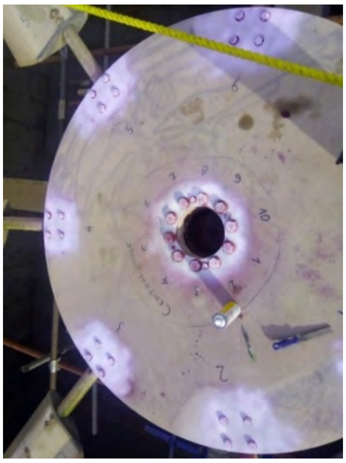

Figure 8 Critical places on the top holder for blades after evaluation of surface irregularity

Figure 9 Critical place holder-blade evaluation of volume irregularity by using conventional ultrasonic method

Figure 10 Critical place holder-blade evaluation of volume irregularity by using conventional ultrasonic method

Figure 11 Critical area holder-reducer assessment of volume irregularities by conventional ultrasound method

Figure 12 Critical area holder-reducer assessment of volume irregularities by conventional ultrasound method

On that occasion, volume irregularities of small dimensions were observed in the area of the threaded joints that connect the blades to the blade holder (Figures 9, 10) and volume irregularities of small dimensions in the area of the screw joints that connect the blade holder to the reducer (Figures 11 and 12) based on the relevant amplitude (peaks) of ultrasonic waves. The heights of these amplitudes were evaluated in relation to the reference energy level of the ultrasound waves. Based on the estimated amplitudes, it was determined that the irregularities are of small dimensions and that their monitoring is currently recommended.

4 Electric motor checking during service life

Testing the electric motor at nominal load is an important stage in the servicing of electrical equipment. This process helps to ensure that the engine is running properly and is ready to go. During the check, it is necessary to pay attention to the stability of the current, the absence of overload and the heating of the motor. Such measures help prevent accidents and ensure a long working life of the electric motor, which is important for the continuity of the entire drive. In the event that some of the parameters deviate from the permitted values, the engine must be sent for a detailed search and eventual overhaul.

5 Conclusions

The adopted method of examination of blades holder presents a very flexible variant and a unique solution to the previously described problem, which, with relatively low financial resources and with the practical possession of simpler conventional ultrasonic devices and a set of penetrants (excepting the need for a certification body for personnel), enables the owners-users of oil and gas facilities to check the actual the condition of the blade holder of the axial fan of the water cooling tower (in the available weather conditions for inspection) which are, as a rule, devices necessary for the smooth running of the production process of crude oil and gas processing.

By applying this methodology additional savings on the plants are realized, because this approach allows them to see the actual condition of the blade holders (practically once a year), which avoids potential breakages of the blade holders and unforeseen downtimes that follow as a rule after that. This enables the timely repair of the holders or the replacement of the blade holders, which avoids high economic losses, especially in desert or remote plants where the procurement and transport of new parts is difficult. In addition, it is necessary to mention that in oil/gas plants, the cooling tower often consists of two sections, so in winter conditions, depending on the nature of the process, it is possible to redirect the entire process to one section of the cooling tower, thus creating an additional opportunity for checking the condition of the blades holders in relation to the scheduled period of regular maintenance.

Application of this method will increase the energy efficiency of the entire cooling tower, which is of great importance from the aspect of renewable energy sources.

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