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EFFICIENCY OF COOLING SYSTEM IMPLEMENTATION FOR MAGNETRON ANODE BLOCK IN INDUSTRIAL MICROWAVE INSTALLATIONS

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There are patterns in the interaction between a microwave electromagnetic field and polar dielectrics, for example, the volumetric heating of a material and the local heating. As a result, microwave treatment could lead to new effects and the emergence of unique properties of materials [1–3]. Microwave technologies are attractive in that they make it possible to obtain qualitatively new materials, which is impossible to achieve by using other thermal processing methods. In this regard, there is understandable interest in the use of microwave heating, which has been particularly active in recent times. Accordingly, there has been increased interest in the construction of industrial microwave devices, which is associated with a significant reduction in the cost of components for microwave equipment. Microwave (dielectric) heating that employs energy of an alternating electromagnetic field in the microwave range is promising for use in various industries [4, 5]. Feasibility of microwave heating is predetermined by a series of indicators, which include [6]:

– a possibility of instantaneous managed heating or local heating;

– reduced space allocated for storage or equipment resulting from a significant decrease in the processing cycle;

– less shrinkage and lower losses during treatment;

– better quality of treated products;

– significant reduction in heat losses into the environment and reducing its pollution;

– high bactericidal effect of microwave energy;

– inertia-free heating and a possibility to fully automate the process. However, the introduction of microwave technology is inhibited by some unresolved important technical issues. One of these is the task on ensuring a thermal mode for a microwave energy generator. In this case, the issue on providing a thermal regime for the magnetron should be paid more attention since an increase in the anode unit's surface temperature above permissible leads to a rapid failure in the generator operation. Anode unit is the main part of the magnetron. The anode unit consists of a copper cylinder, with cavities in the center, which are a ring cavity resonator system. The magnetron's electron efficiency, which defines the efficiency of an electron flux energy conversion into the energy of high-frequency fluctuations, is quite high (up to 80 %), but almost all remaining part is released in the form of heat on the anode unit that causes its heating. To cool it, ribbed radiators are mounted at the surface of low-power magnetrons, which are manufactured for microwave ovens. There is some interest in the use of such magnetrons for industrial installations, which necessitates making their cooling system more reliable. Industrially-produced low-power magnetrons are designed for household microwave ovens. When they are used at industrial installations, such magnetrons often overheat and fail. In this case, the appropriateness of their application relates to that they are quite reliable (subject to maintaining thermal regimes) and are much cheaper than magnetrons at high output power. In addition, a uniform distribution of microwave energy is easier to achieve by applying several low-power magnetrons rather than one of high power. The task on maintaining steady thermal mode for magnetrons with an output power up to 1 kW at their long-term use at industrial installations could be solved by replacing an air-cooling system (ACS) with the system of liquid cooling (SLC). In this case, it is necessary to substitute the ribs that are installed on the anode unit with a cooling jacket, tightly fitted to the surface of the anode. Transition to SLC must be accompanied by thermal engineering calculations, the result of which would be to define the operating parameters for the system. The relevance of the current work relates to that the system that maintains thermal modes (SMTM) at low-power magnetrons currently produced has not been modernized up to now, because their application was limited to operating conditions for household microwave ovens. A system of air cooling is more suitable for a brief operation under household conditions, but, when used industrially, it does not warrant reliability in maintaining the required temperature regime.

An optimal system to ensure thermal mode for magnetrons, which are part of the devices for heat treatment of materials during continuous and prolonged operation is the system of liquid cooling with a closed-loop circulation. The proposed replacement of the air-cooling system with the liquid system for low-power magnetrons would make it possible to stabilize temperature and improve reliability of the device. This implies installing a cooling jacket directly to the anode unit. The intensive heat exchange requires that the thermal resistance in a cooling jacket and the anode unit's surface should be maximally reduced. Our calculations show that the temperature difference in the place of contact between the anode unit's surfaces and the cooling jacket at a thickness of the gap of 0.5 mm, considering contact resistance, does not exceed 0.3°C. To calculate a heat transfer coefficient, we have proposed empirical dependence (5) derived from results of thermal experiments using a model. The use of water as a heat-carrier increases a heat transfer coefficient by 2.1 times compared with a 54% aqueous solution of ethylene glycol. This is due to the difference in the thermophysical properties. The heat transfer coefficient, taking into consideration the thermal resistance of the anode unit, is 1.9 times higher for water. Thus, using water appears to be preferable. However, at negative ambient temperatures it is recommended to fill the system of liquid cooling with aqueous solutions of ethylene glycol. Merits of the current research are in that the conditions for establishing an estimated dependence were maximally close to actual thermal processes in the cooling jacket that makes it possible to obtain reliable estimates for such systems. It should also be noted that the proposed scheme for SLC implies application of multiple magnetrons, which is important in order to ensure the uniformity of heating a material in the device. The limitation of the current study is that the calculations were carried out for the magnetron with a power output of 1 kW, while it is possible to use low-power magnetrons with other characteristics. In the future, it is advisable to consider the influence of geometric characteristics of a cooling channel on the intensity of heat transfer, as well as to undertake a research using a field sample in order to refine the estimates.

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ВИКОРИСТАННЯ ВОДОРОДУ ЯК АЛЬТЕРНАТИВНОГО ПАЛИВА ДЛЯ МОРСЬКОГО ФЛОТУ СЬОГОДНІ ТА В МАЙБУТНЬОМУ

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197 країн в 1915 році підписали Паризьку угоду по захисту клімату. Глобальне потепління відбувається через підвищення викидів CO_2. В доповідях в ООН в 2018 році було приведено кількість викидів 55,3 гігатонн. При таких темпах забруднення довкілля, до кінця століття температура на Землі зможе підвищитися на 3,2 градуси, це повне