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INDUCTION METOD FOR HEATING OIL IN LOW PRODUCTION WELLS

Abstract. The article discusses the induction method of heating oil in low production wells. To do this, it was suggested to use induction heater and frequency converter. Shown that at current frequencies of 1 - 1.5 kHz, an induction heater and inverter frequency converter can be installed at the bottom of oil wells. The inverter will be made on a JGBT transistor modules that can switch voltages up to a thousand volts, currents of hundreds of amperes and tens of kilowatts of power.

The goal of the research is to heat the oil to the required temperature, with the most efficient use of the consumed electricity, without the use of an open flame (furnace, burner), without thermal electric heaters (TENs), and without the use of heat exchangers, the efficiency of which does not exceed 60-80%. This is possible using the induction heating method.

Induction heating is used to heat technological equipment (oil pipelines, pipelines, tanks, etc.), heat liquid media, and dry coatings of materials (for example, wood). The most important parameter of induction heating settings is frequency.

For each process, there is an optimal frequency range that provides the best technological and economic indicators. For induction heating, frequencies from 50 Hz to 5 MHz are used. The advantages of induction heating.

The principle of operation of induction heaters is simple. If a metal work piece or parts are placed in an alternating magnetic field, then, according to the law of electromagnetic induction, an electromotive force is induced in it, under the influence of which an alternating electric eddy current will flow.

This current will heat the body of this work piece or part to the required temperature.

The general concept of the article is that with the help of an induction heater it is possible to heat oil in oil wells, and thus, increase oil production in low flow wells, that is, increase the profitability of oil production.

Key words: the induction method, at current frequencies, JGBT transistor modules, voltages, the required temperature, of this work piece.

Introduction. According to the Committee of the State Duma of Russia on energy, transport and communications, more than 70 % of the reserves of oil companies are in the range of low rates, that is, on the verge of profitability [1]. The share of hard-to-recover reserves reached 55-60 % and continues to increase. If 15 years ago 55 % of wells produced up to 25 tons of oil per day, today only about 10 tons are produced. Water cut is increasing (the amount of water pumped into the oil reservoir to increase pressure). The same situation is in Kazakhstan.

To increase oil production, it is necessary to heat the oil. This is a multifaceted and serious problem for many oil companies. Different heat carriers are used for heating: steam, hot water, hot gases and oil products, electric energy.

The greatest application is water vapor, which has the highest heat content and heat transfer, is simply transportable and does not pose a fire hazard. They use saturated steam with a pressure of 0.3-0.4 MPa, providing oil heating to 80-100 °C.

To heat the oil, electric heating devices are used, which differ in compactness, ease of maintenance and benefit when cheap electricity is available.

The goal of the research is to heat the oil to the required temperature, with the most efficient use of the consumed electricity, without the use of an open flame (furnace, burner), without thermal electric heaters (TENs), and without the use of heat exchangers, the efficiency of which does not exceed 60-80 %. This is possible using the induction heating method. Induction heating is used to heat technological equipment (oil pipelines, pipelines, tanks, etc.), heat liquid media, and dry coatings of materials (for example, wood). The most important parameter of induction heating settings is frequency [2].

For each process, there is an optimal frequency range that provides the best technological and economic indicators. For induction heating, frequencies from 50 Hz to 5 MHz are used.

The advantages of induction heating.

Electric energy is transferred directly to the heated body and allows direct heating of materials, with an increase in the heating rate.

1. The transfer of electrical energy directly to the heated body occurs in a non-contact manner. This is convenient in conditions of regulating the heating temperature and for automating the heating process.

2. Due to the phenomenon of the surface effect, maximum power is released on the surface layer of the heated product. Therefore, induction heating provides fast heating of the product and is more economical than other methods of heating oil.

3. Induction heating in most cases makes it possible to reduce the overall dimensions of the heated material at high current frequencies [3].

Description of the essence of development and testing methods. This method of heating oil in oil wells is used in Latin America. As a review and analysis of the literature, as well as technical documentation shows, the unit cost of existing foreign designs of heaters is very high.

In this regard, the introduction of foreign-made heaters in Kazakhstan is unprofitable, since the payback period reaches about ten years. Therefore, you should develop your own induction heaters based on your own developments, which will be cost-effective.

Given that at a low cost of electricity compared to the cost of electricity abroad, as well as a decrease in the unit cost of the entire installation, the development and implementation of induction heaters is an urgent problem. The article proposes an induction heater and a frequency converter on JGBT transistor modules. Moreover, the design is simpler and more technologically advanced for manufacturing, and they can be manufactured, assembled and tested at enterprises in Kazakhstan [4].

In addition, the developed technology and design methods allow you to create an individual induction heater for a specific type of oil heating process.

Modern induction heaters are classified according to the range of operating frequencies, which determine the scope of induction installations.

The principle of operation of induction heaters is simple. If a metal workpiece or parts are placed in an alternating magnetic field, then, according to the law of electromagnetic induction, an electromotive force is induced in it, under the influence of which an alternating electric eddy current will flow.

This current will heat the body of this workpiece or part to the required temperature. The general concept of the article is that with the help of an induction heater it is possible to heat oil in oil wells, and thus, increase oil production in low flow wells, that is, increase the profitability of oil production.

To do this, it will be necessary to develop various designs of the induction heater and frequency converter on JGBT transistor modules. The induction heater will be located at the bottom of the oil well and must be leakproof as well as corrosion resistant. As a rule, a frequency converter consists of a rectifier and an inverter. The rectifier will be connected to a three-phase AC voltage source and will be located on the surface of the earth, and the inverter at the bottom of the oil well with an induction heater.

This simplifies the method of supplying electricity to the bottom of the oil well, since the electricity from the rectifier is supplied by DC voltage. Calculations showed that the overall dimensions of the JGBT transistors and transistor modules can be placed at the bottom of the oil well with oil pipes with a diameter of 150-200 mm.

The design of the induction heater, which will be located at the bottom of the oil well, is a metal pipe. The main purpose of the induction heater is to create an electromagnetic field of any configuration in order to create eddy currents in the heater core. In general, an induction heater is an energy converter that converts electricity to heat [2].

Test results and discussion. If an induction heater is considered as an electric machine converter with a braked rotor, then it will convert electric energy into thermal energy [3].

In this case, the heater will have basic main dimensions: the outer diameter D1 and the inner diameter D2, the estimated length L, the base power $\mathbf{P}_б$, frequency f. The sizes D1, D2 and L are related to power, frequency f and electromagnetic loads ¬ following expression [5]

$$\frac{D^2L\cdot f}{P_б}=\frac{6{,}1\cdot 10^{11}}{k_B k_{об} A\cdot B}, \quad (1)$$

where: A- is the linear load of the heater, B- is the induction in the core of the heater, $\mathbf{k}_B$ = 1.1 is the coefficient of the shape of the voltage curve, $к_{об}$ = 0.95 is the winding coefficient.

The base power of an induction heater is

$$P_б = P_н \frac{k_E}{\eta\cos\varphi} \quad (2)$$

where Pn- is the rated power of the induction heater, kW; k_E - the ratio of the EMF of the heater winding to the nominal voltage, which can be approximately determined from = 0.93 - 0.98. [6]. The values of efficiency η = 0.88 and power factor cos φ = 0.85 can be taken according to.

Then the rated current is

$$I_{1н}=\frac{P_н}{U_1\cdot\eta\cdot\cos\varphi}=\frac{25000}{514\cdot 0{,}88\cdot 0{,}85}=65A \quad (3)$$

where U1 = 514 V is the rated voltage of the induction heater.

The preliminary selection of electromagnetic loads A, Bb, must be carried out very carefully, since they determine not only the calculated length of the heater, but also, to a large extent, the characteristics of the heater. When choosing specific values of A and Bb from practice, they are guided by the following data: A = 300 A / cm and Bb = 8,000 Gs = 0.8 Tc.

Then from the expression (1) for a given value of the outer diameter

D1 = 150 mm can determine the length of the heater

$$L=\frac{6{,}1\cdot 10^{11}\cdot P_б}{k_B k_{об} A\cdot B\cdot D^2\cdot f}, \quad (4)$$

For a given rated power Pn = 25 kW and frequencies f = 2000 Hz, also with the above values of efficiency η = 0.88, power factor cos φ = 0.85 and $\mathbf{k}_E$ = 0.95, the base power will be equal to

$$P_б = P_н \frac{k_E}{\eta\cos\varphi} = 25\frac{0{,}95}{0{,}88\cdot 085}=31{,}78kW.$$

In this case, the length of the heater will be equal to

$$L=\frac{6{,}1\cdot 10^{11}\cdot 31{,}78}{1{,}1\cdot 0{,}95\cdot 300\cdot 8000\cdot 15^2\cdot 2000}=17{,}17sm.$$

Preliminary calculations show that an induction heater with a rated power of Pн = 25 kW, an outer diameter of D1 = 150 mm, a length of L = 171.7 mm at a frequency of f = 2000 Hz can be freely placed at the bottom of the oil well. Naturally, at other frequencies these sizes will be different.

Table 1 presents the dependence of the length L of the induction heater on the frequency f for a given outer diameter D1 = 150 mm.

Table 1

Current Frequency (f), Hz	50	500	1000	1500	2000
Length of induction heater L, cm	686,8	68,68	34,34	22,89	17,17

When designing an induction heater, it is necessary to take into account the quality of heating, i.e. creating the desired temperature distribution in the heater body and achieving the highest efficiency value, as well as take into account special technological and other requirements in terms of geometric dimensions, materials used, etc.

A variety of heating systems, a limited range of weight and size parameters and the specificity of the oil heating process lead to the fact that the design of the induction heater is very diverse. [6].

Designing a workable induction heater with minimum weight and size parameters that increases the efficiency and power factor is not an easy task.

The duration of induction heating of the heater is associated with a number of factors. From the point of view of productivity and installation efficiency, the heating time should be as short as possible.

However, with very fast heating, a significant temperature difference is obtained between the surface and the center of the heater billet.

The calculation of the induction heater consists in choosing the current frequency, determining the heating time, calculating the dimensions (diameter and length) of the heater, determining the required power of the frequency converter and the capacitance of the capacitor.

The initial data are the material and sizes of the heater, as well as the heating time.

The mass of the induction heater is determined as follows

$$G = \rho_{мет} \cdot \pi \cdot \left(R_1^2 - R_2^2\right) \cdot L \ , \qquad (5)$$

where $\rho_{мет} = 7880$ kg / m^3 - is the specific gravity of the metal, R1 and R2 are the outer and inner radii of the heater, in m; L is the length of the heater, in m.

With the above parameters, the mass of the heater will be equal to

$$G = 7880 \cdot 3{,}14 \cdot \left(0{,}15^2 - 0{,}075^2\right) \cdot 0{,}1717 = 71{,}69 kg$$

At a given heating temperature, in degrees C, the required rated power for heating the induction heater is determined by the following expression, according to [7].

$$P_н = \frac{c_0^{1200} t_{нагр} \cdot G}{\tau_{нагр}} \text{, kW} \qquad (6)$$

where $\mathbf{c_0^{1200}}$- the average heat capacity of steel is 0.704 kJ / kg. hail.

From the last expressions, it is possible to determine the heating $\tau_{нагр}$ time in seconds at a given heating temperature $\tau_{нагр}$

$$\tau_{нагр} = \frac{c_0^{1200} t_{нагр} \cdot G}{P_н} . \qquad (7)$$

Taking into account the above data and at a given heating temperature tnag = 3000 C, the heating time $\tau_{нагр}$ will be equal to

$$\tau_{нагр} = \frac{0{,}704 \cdot 300 \cdot 71{,}69}{25{,}0} = 605{,}6c = 10{,}1 \min$$

It turns out the actual heating time of the induction heater is 10.1 minutes.

Table 2 presents the dependence of the heating time of the induction heater on frequency.

Table 2

Induction heater heating time, min.	403,8	40,38	20,2	13,5	10,1
Current Frequency (f), Hz	50	500	1000	1500	2000

When induction heating of metal billets, the frequency is selected based on the maximum efficiency [6]. In this case, the current frequency must be selected based on the optimal weight and dimensions of the induction heater and the heating time. As can be seen from tables 1 and 2, the industrial frequency of 50 Hz is not suitable, since the induction heater will have a length of 6.87 meters and a heating time of 403.8 minutes or 6.73 hours.

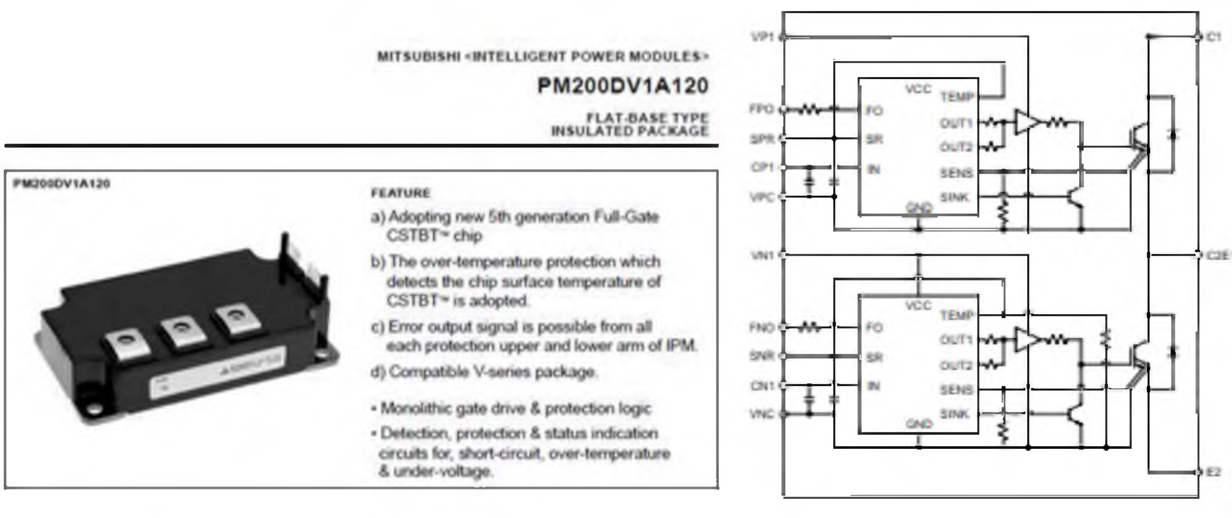
The optimal frequency is 1000-1500 Hz, while the length of the induction heater is 34.34-22.89 cm and the heating time is 20.2-13.5 minutes. Such a frequency is acceptable for switching transistors.

Transistor frequency converters of induction units consist of a rectifier and an inverter [7]. The technology for creating a rectifier on diodes and thyristors is known and well developed. Of interest is an inverter that will be implemented on transistor JGBT modules.

In most cases, the frequency converter runs on four transistors. In this case, it can be performed on two transistors. This idea was patented in the intellectual property committee of the Republic of Kazakhstan [3]. Two transistors can be successfully placed at the bottom of the oil well. It should be noted that the main losses of electricity occur in transistors and with a decrease in half, respectively, increases the efficiency of the frequency converter.

MITSUBISHI's VIPM Series Intelligent Power Modules (IPMs), which are a new stage in the development of power switches based on IGBT modules, are now a functionally complete product in a compact, insulated enclosure [8].

Figure shows the IGBT transistor module from MITSUBISHI, in table 3 - operational characteristics. As can be seen from table 3, these transistors are designed for high voltages, currents and powers. A frequency converter made on these transistor modules allows heating oil in oil wells.



IGBT module of the MITSUBISHI PM200DV1A120 transistor
with an integrated control driver and a wiring diagram

Table 3

Name	Parameters			Scheme
	V_{ces}(V)	I_C(A)	P_0(kW)	
PM200DVA120	1200	200	37	D
PM300DVA120	1200	300	55	D
PM400DVA060	600	400	45	D
PM600DVA060	600	600	55	D
PM75CVA120	1200	75	15	C
PM100CVA060	600	100	11	C
PM100CVA120	1200	100	22	C
Designations: V_{ces} – supply voltage, I_C – load current, P_0 – recommended power delivered to the load.				

The overall dimensions of the transistor module are completely located at the bottom of the oil well. At the same time, the supply voltage is 514 V, the load current is 65 A and the load power of 25 kW is quite acceptable for the transistor module with a margin.

An inverter made on transistor JGBT modules is controlled by control drivers [7]. The term "driver" refers to a microcircuit or module on a printed circuit board that controls a semiconductor power module or a discrete semiconductor device (MOSFET, IGBT, bipolar transistor, thyristor, etc.) that perform protective and service functions. The main task solved by the control circuit is to match the levels of pulses generated by the controller (microprocessor) with the control signals of the power key inputs, which require some power to turn on and off.

There is experience in the development and manufacture of an inverter with microprocessor control for converting direct current solar energy into alternating voltage energy [8]. In [9], the results of a developed and manufactured experimental model of a frequency converter with microprocessor control for induction heating of metal are presented.

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ТӨМЕН ӨНДІРУ ҰҢҒЫМАЛАРЫНДА МҰНАЙДЫ ҚЫЗДЫРУДЫҢ ИНДУКЦИЯЛЫҚ ӘДІСІ

Аннотоция. Мақалада томен өндірістік ұңғымаларда мұнайды қыздырудың индукциялық әдісі қарастырылады. Ол үшін индукциялық қыздыргышты және жиілік түрлендіргішін пайдалану ұсынады. Көрсетілген токтың 1-1,5 кГц жиіліктерінде индукциялық жылытқыш және мұнай ұңғымаларының түбінде инвертор жиілігін түрлендіргіш орнатылуы мүмкін. Инвертор JGBT транзисторында кернеуді мың вольтке дейін ауыстыра алатын модульдер, жүздеген ампер мен ондаған киловатт қуат жасалады.

Мұнайды жылыту үшін ықшамдылық, техникалық қызмет корсету қарапайымдылыгы және арзан электр қуаты болган кезде пайдасы бойынша ерекшеленетін электр жылыту құрылғылары қолданылады.

Жүргізілген зерттеулердің мақсаты – мұнайды қажетті температураға дейін, жұмсалатын электр энергиясын барынша тиімді пайдалана отырып, ашық отты (пештерді, жанаргыларды) қолданбай, жылу электр қыздыргыш аспаптарынсыз (Тэндерді) және ПӘК 60-80 %-дан аспайтын жылу алмастыргыш құрылғыларды пайдаланбай қыздыру. Бұл индукциялық қыздыру әдісін қолдану арқылы жүзеге асуы мүмкін.

Индукциялық қыздыру технологиялық жабдықты (мұнай құбырлары, құбырлар, резервуарлар және т.б.), жылу сұйық ортасын және материалдардың құргақ жабындарын (мысалы, агаш) жылыту үшін қолданылады. Индукциялық қыздырудың маңызды параметрі – жиілік. Әрбір процесс үшін ең жақсы технологиялық және экономикалық көрсеткіштерді қамтамасыз ететін оңтайлы жиілік диапазоны бар. Индукциялық қыздыру үшін 50 Гц-тен 5 МГц-ге дейінгі жиілік қолданылады.

Мұнай өндірісін арттыру үшін майды жылыту керек. Бұл – коптеген мұнай компаниялары үшін жан-жақты және маңызды проблема. Жылыту үшін әртүрлі жылу тасымалдагыштар қолданылады: бу, ыстық су, ыстық газдар мен мұнай өнімдері, электр энергиясы. Ең коп қолдануға болатыны – су буы, ол ең коп жылу мөлшері мен жылу өткізгіштікке ие, жай гана тасымалданады және орт қауіпін тудырмайды. Олар 0,3-0,4 МПа қысыммен қаныққан буды пайдаланады, мұнайды 80-100 °С-қа дейін қыздырады.

Мақалада JGBT транзисторлық модульдеріндегі индукциялық жылытқыш және жиілік түрлендіргіші ұсынылған. Сонымен қатар дизайн қарапайым және технологиялық тұргыдан жетілдірілген. Оларды Қазақстанның кәсіпорындарында дайындауға, жинауға және сынақтан откізуге болады. Сонымен қатар әзірленген технология мен дизайн әдістері майды қыздыру процесінің белгілі бір түріне жеке индукциялық жылытқыш құруга мүмкіндік береді.

Мақаланың жалпы тұжырымдамасы: индукциялық жылытқыштың көмегімен мұнай ұңғымаларында майды жылытуға болады, сөйтіп томен агынды ұңғымаларда мұнай өндірісін кобейтуге болады, ягни мұнай өндірудің рентабельділігін арттырады.

Металды индукционды қыздыру үшін арзан тұратын пайдалы әсер коэффициенті жогары габариті және салмағы аз жиілік түрлендіргіштер қолданылады. Олар жиілік түрлендіргіштердің диапазонын реттеуге, күштік транзисторлардың минималды санын таңдауды және орнатылган минималды қуаттарды қамтамасыз

етеді. Жиілік түрлендіргіш пен индуктордың тәжірибелік үлгісі дайындалған. Индукционды металды қыздыру үшін жиілік түрлендіргіштің эксперименталдық зерттеулері жүргізілген.

Түйін сөздер: осы жиіліктегі индукция әдісі, транзистордың JGBT модульдері, кернеулер, қажетті жұмыс температурасы.

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ИНДУКЦИОННЫЙ СПОСОБ НАГРЕВА НЕФТИ В НИЗКОДЕБИТНЫХ СКВАЖИНАХ

Аннотоция. В статье рассматривается индукционный способ нагрева нефти в низкодебитных скважинах. Для этого предлагают использовать индукционный нагреватель и преобразователь частоты. Показано, что при частотах тока 1 – 1,5 кГц индукционный нагреватель и инвертор - преобразователь частоты могут быть установлены на дне нефтескважин. Инвертор будет выполнен на JGBT транзисторных модулях, которые могут коммутировать напряжения до тысячи вольт, токи сотни ампер и десятки киловатт мощности.

Для подогрева нефти используют электронагревательные устройства, которые различаются компактностью, удобством в обслуживании и выгодой при наличии дешевой электроэнергии.

Цель проводимых исследований – нагрев нефти до необходимой температуры, с максимально эффективным использованием затрачиваемой электроэнергии, без применения открытого огня (печи, горелки), без тепловых электронагревательных приборов (ТЭНов) и без использования теплообменных устройств, КПД которых не превышает 60-80%. Это возможно при использовании индукционного способа нагрева

Индукционный нагрев применяют для обогрева технологического оборудования (нефтепровода, трубопровода, емкости и т. д.), нагрева жидких сред, сушки покрытий материалов (например, древесины). Важнейший параметр установок индукционного нагрева – частота. Для каждого процесса существует оптимальный диапазон частот, обеспечивающий наилучшие технологические и экономические показатели. Для индукционного нагрева используют частоты от 50Гц до 5Мгц.

Для увеличения добычи нефти необходимо осуществить подогрев нефти. Это многогранная и серьезная проблема для многих нефтедобывающих компаний. Для обогрева используют разные теплоносители: водяной пар, жаркую воду, жаркие газы и нефтепродукты, электроэнергию. Наибольшее применение имеет водяной пар, обладающий высочайшим теплосодержанием и теплоотдачей, просто транспортируемый и не представляющий пожарной угрозы. Употребляют насыщенный пар давлением 0,3-0,4 МПа, обеспечивая нагрев нефтепродукта до 80-100 °С.

Такой способ нагрева нефти в нефтескважинах применяется в странах Латинской Америки. Как показывает обзор и анализ литературы, а также технические документации, удельная стоимость существующих зарубежных конструкций нагревателей очень высока. В связи с этим, внедрение нагревателей в Казахстане иностранного производства невыгодно, так как срок окупаемости достигает около десяти лет. Поэтому следует разрабатывать свои индукционные нагреватели на основе собственных разработок, которые будут экономически выгодны. Учитывая, что при низкой стоимости электроэнергии по сравнению со стоимостью электроэнергии за рубежом, а также снижение удельной стоимости всей установки, разработка и внедрение индукционных нагревателей является актуальной проблемой.

При разработке технической документации для изготовления лабораторного образца преобразователя частоты и выборе транзисторных JGBT модулей основное внимание было уделено топологии силовых шин модуля и способам подключения электрических цепей и отвода тепла. Даже при использовании самых современных чипов конструкция мощных ключевых модулей имеет чрезвычайно большое значение для обеспечения надежности и эффективности. Распределенные характеристики проводимости и значения паразитных индуктивностей шин связи и выводов должны иметь минимальное значение для уменьшения потерь и снижения уровня переходных перенапряжений.

Кроме того, подбирая экспериментальный путем значение конденсатора С, можно не только улучшить качество выходного напряжения, но и добиться последовательного резонанса. При резонансе активная мощность инвертора будет передаваться индуктору, т.е. заготовке для нагрева.

Ключевые слова: индукционный метод, на частотах тока, транзисторные модули JGBT, напряжения, требуемая температура этой детали

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