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Presenting a Suitable Method for Protecting Electromagnetic Field on Rebars of RC Foundation

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Abstract

Electrical reactors used in the power industry are equipment that typically includes multiple coils, and a high electric current passes through to about a few kilo amperes. In accordance with the technical specifications, dimensions, structure and physical shape of the equipment, magnetic fields are formed around them. The magnetic field of this equipment can affect the steel structure of the foundation and its retaining reinforcement concrete structures and cause the induction of the voltage of the rotary and stray electrical currents in the rebar mesh and the heat losses and metal components of the reactor foundation. Mechanical stresses caused by generated heat in steel rebars can cause failure, cracks and reduction of reinforced concrete durability. In this research, the reinforced concrete foundation of Tyristor Controlled Reactors by exposed to a low-frequency magnetic field and a relatively large flux density is simulated and analyzed using the ANSYS Workbench software. The amount and distribution of temperature and mechanical stress in the foundation were obtained and the results of software output were compared with the scientific criteria of fraction and failure. Then, four methods were evaluated for constructing a reactor foundation include the use of fiber reinforced polymer rebars, the use of steel rebars by insulation of their contact points with electrical insulating materials, such as polyvinyl chloride, the use of non-magnetic rebar type 304 and the use of Fiber Concrete with cost criteria, time and quality. Based on the results, the method of using steel rebar along with insulating their contact points and considering the electrical and thermal clearance of the reactor is economically feasible and is applicable at a shorter time and is technically acceptable.

Keywords: Reactor, Magnetic Field, Reinforced Concrete Foundation, Simulation, ANSYS

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1. Introduction

The magnetic field of electric reactors can affect the foundation steel components and structures and cause the induction of voltage and the generation of rotary and eddy electrical current flows in the rebars of mesh and the thermal losses in the metal components of the reactor foundation (Charpin et al., 2021). Mechanical stresses caused by heat generated in steel rebars can cause failure, cracking, and reduction of RC (Reinforcement Concrete) durability (Chakraborty et al., 2017). In this research, the RC foundation of the Tyristor Controlled Reactor (TCR) is simulated and analyzed using ANSYS Workbench software. The amount and distribution of temperature and mechanical stresses in the foundation have been obtained and the output results of the software have been compared with the scientific criteria of failure and fracture. Due to the expected electrical behavior, dimensions, structure and physical shape of the equipment, there is a relatively large magnetic field around them (Xiu et al., 2020). The variable magnetic flux with the time of the operation of the equipment passes through its surrounding components and induces the voltage in the metal objects (here means the steel objects), whereas if the metal components are in the form of a closed ring, this voltage cause the electric current to flow into the closed metal loop and when the magnetic flux density flowing through the loop is high, because of the low metal loop resistance, a relatively large rotational current developed in the loop and as a result, electrical losses are proportional to the second power of the current in the loop. The thermal effects due to the application of a low-frequency magnetic field and a relatively high magnetic flux density of electric reactors can lead to failure, cracking, and reduction in RC foundation durability (Mitarai et al., 2019). The magnetic field of electrical reactors, especially the TCR, can have undesirable effects on the specifications and electrical behavior of the equipment. In general, the important and influential phenomena arising from the interaction of magnetic field and reinforced concrete structures are: (a) induction of voltage in closed metal loops and generation of rotary currents and the occurrence of ohm losses in steel and thermal stresses due to heat in a concrete structure of the reactor, (b) the interaction between the reactor and the metal components, changes its electrical characteristics and the electrical behavior of the reactor. In addition, the electrical losses generated in the rebar mesh cause energy wastage (Sun et al., 2022).

The harmful effects of magnetic fields caused by the operation of electric reactors should be limited or ineffective by applying appropriate technical and economic methods and procedures. In this research, the thermal and mechanical effects of magnetic fields of TCR on its foundation were simulated, analyzed and studied using ANSYS. Investigating the magnetic behavior of the reactor, as well as the thermal and mechanical behavior of the RC foundation through software modeling and analysis, can help to identify the ambiguous aspects of its designing and implementing. Nowadays, due to the ease of access to powerful software for simulation magnetic, thermal and mechanical analysis, it is necessary to use the facilities in solving technical problems of the project. The main question of this research is whether the electromagnetic field caused by the reactors can cause damage to the RC with the steel rebar. In this research, four common methods of constructing concrete reactors foundation with cost, time and quality criteria were evaluated and compared and a suitable method among them was selected and introduced. A case study was carried out on air-type TCR of compensating systems. Because it has the highest magnetic field flux density. Electric reactors consist essentially of one or more coils of copper or aluminum, and in general, the electric current in their coil causes a magnetic field around the flow path. The magnetic field of the reactor is proportional to the electric current and the geometry and in contradiction with the hypothetical interval point in space with the carrier current conductor and a quantitative vector. Electric reactors generally include oil reactors and dry (aerial) reactors. Reactors have an aerial core called dry or aerial type. Electric reactors have different types depending on the application and expected electrical behavior is given in Table 1.

Table 1: different types and applicable of the electrical reactor

Type of reactor	Applicable	`
TCR	Use as compensator of reactive power as a controlled reactive power supply	studied
Series	Stabilizing of current and reduce of melting electrode consumption.	-
Shunt	Useable in power grid for stabilizing of voltage.	-
Filter	Useable in electrical filters for eliminate harmonics of voltage and current.	-

The reactor is used to compensate reactive power as a reactive power source TCR is investigated in this research. The total schematic of the TCR is shown in Figure1.

Figure 1: TCR electrical portion and foundation

2. Materials and Methods

2.1 Electrical issues

The reactor is a special device, the manufacturer's instructions should be carefully consider by the designer, installer and operator in order to limit the environmental and human impacts of the fields as much as possible. In the manufacturer's technical catalog, the values for the height and intervals of reactors installation and accessories and their adjacent equipment are recommended. At these intervals, in addition to the magnetic considerations, other parameters such as the zone of electric field, the minimum intervals for ventilation and cooling are also included. The technical instructions refer to two types of Magnetic Clearance (MC) The first zone is a boundary in which no metal object, either with closed metal loop or without a metal loop, should exist.

2.2 Safety coefficients and circumstances criteria of material failure and fracture in ANSYS software

ANSYS, in addition to having the ability to simulate the magnetic field and calculating the losses in metal components of the reactor foundation, can analyze the thermal behavior of the concrete and the steel rebar of the reactor foundation. The software will use tools and safety co-efficiencies to predict the failure and fracture of materials in accordance with the following. These definitions and criteria are derived from the ANSYS software guide. Since the vector of stress at any point, in addition to the position of the point, depends on the direction of the desired level of the same point, it is asked which stress vector on which of the levels passed from the point P, finds its own maximum or minimum. The vector of stress on the surface or surfaces will reach the maximum or minimum so that the shear stress on those surfaces is eliminated. These levels are the main levels and the stress on those surfaces is called the main stresses. The main surfaces or vertical stress levels, maximum and minimum, two by two are orthogonal. Equivalent stress is connected to the main stresses with the Equation (1) (Cheng, 2013).

$$\sigma_e = [\,(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]^{1/2} \quad (1)$$

where σ_e Equal stress, σ_1 maximum main stress, σ_2 middle main stress, σ_3 main stress is minimum. The ANSYS uses the following criteria to break down objects. These criteria have been introduced as Safety tools.

2.3 Maximum safety tools

Safety tolls of the maximum tensile stress is based on the maximum failure theory of tensile stress and is used for materials such as glass, concrete and porcelain. The failure theory of the maximum tensile stress is typically used to predict failure in brittle materials with static load. According to Equation (2), this theory states that a failure occurs when the maximum stress is equal to or greater than the stress determined by the analyst.

$$\frac{\sigma_1}{S_{limit}} < 1 \quad (2)$$

where σ_1 is the maximum main stress and S_{limit} is the strength of the object determined by the analyst and can be the ultimate stress σ_u and the yelled in stress σ_{yt}.

2.4 Theoretical concept of the Magnetic Field

The main relations and equations governing electromagnetic fields are Maxwell equations. According to Table 2, the two main vectors field in electromagnetic are: magnetic flux density B and magnetic field intensity H. In order to obtain the magnetic flux density due to the flow through the winding of a reactor, the **Biot savart** law of the intensity of the magnetic field is determined in each point in the space (William, 2010; Golmoradi et al., 2023).

Table 2: Electrical and electromagnetic quantities

	Quantities	Symbol	Unit
Electric	Current	I	Ampere
	Voltage	U	Volt
Magnetic	Magnetic flux intensity	B	Tesla
	Magnetic flux	Φ	Weber's

Induced voltage in a conductive loop is obtained according equation 3 (Figure 2).

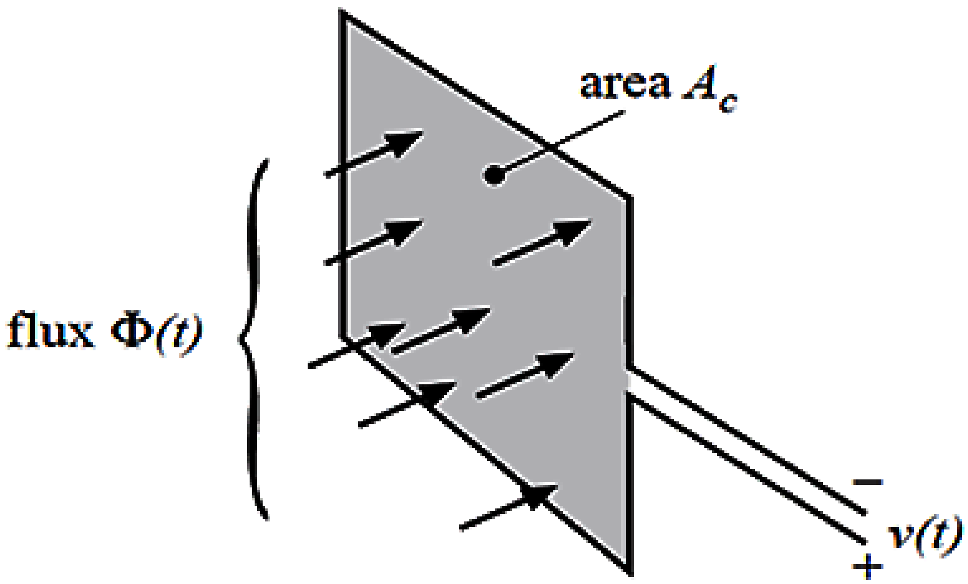

Figure 2: Induce voltage in metal closed loop

$$V(t) = \frac{d\Phi(t)}{dt} \tag{3}$$

where V is the induced voltage in volts and Φ is the variable magnetic flux with time based on Weber's. If the path for rotation of the electric current is established according to Ohm's law, proportional to the voltage and path resistance, the electric current will pass through the loop.

2.5 Heat transfer

Heat transfer is generally carried out in three ways include conduction, displacement and radiation. In most applications, heat transfer is a combination of two or three methods shown in Fig. 3 (Pousti, 2006; Hassan, 2018). If the temperature of the region of the object exceeds the other, the heat flows from the warmer region towards the colder region. This phenomenon is conduction. In this method, the heat transfer medium is inert (solids), so the intensity of the conduction heat transfer (the amount of heat transferred per unit time) is proportional to the slope of the temperature in the body and the size of the heat transfer surface. Thermal conductivity in a medium depends on the geometry, thickness, type, and temperature difference across the environment. If the body level is near a fluid with a different temperature, the temperature is exchanged between the body and the fluid, which defines the heat exchange as heat transfer. The heat transfer coefficient of a displacement is a numerical quantity and does not depend on the direction and is not a component of the fluid, but depends on the geometry of the solid surface, the type of fluid motion, and the volume velocity of the fluid (Figure 3).

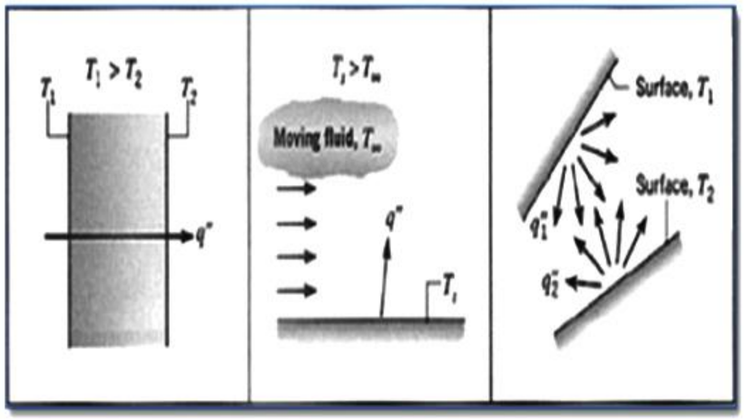

Figure 3: heat transfer in tree way, convection, displacement and radiation [4]

2.6 Research method

According to the objectives and assumptions of the research, the structure of the sample reactor were modeled for electrical, thermal and mechanical design, and the reactor magnetic behavior as well as the thermal and mechanical behavior of its RC foundation were simulated using the ANSYS. Generally, all devices with a type of dry reactor including reactive power compensators, filters and power stations are part of the statistical population of this research, because the mechanism is the same in all. The order and selection of this type was carried out in such a way that the reactor of the reactive power compensation system, which has the highest current flow and, consequently, the maximum flux density of the peripheral magnetic field, is studied. The main variables in this study are the ohm losses required data are obtained from available resources includes books, articles, guidelines and official sites of accredited manufacturers and acquired standards. The physical characteristics of the reactors, directly and with measurements or referring to achieved executive drawings (Table 3). Because having a physical and dimensional characteristic is necessary to construct the geometry of the model, therefore, in order to have the information and physical characteristics, the dimensions are measured in real measure. The size of the rod and the concrete specification and the final concrete thickness of the concrete are also extracted from the executive plans and used in the analysis. ANSYS has a very complete database of physical coefficients, mechanical and thermal constants, and metallurgical properties of materials, but all coefficients, however, can be defined and changed according to the conditions of the subject matter. In this study, consider the values in the real state and in some cases, with the assumption of bad conditions in the analysis and pessimistically. ANSYS has a very comprehensive database of magnetic and electrical properties of materials. Material characteristics in this modeling and analysis (Tables 3 and 4) are generally based on the ANSYS database ANSYS Workbench Software Guideline.

Table 3: TCR and Specimen reactor electrical properties

Item	Properties	Unit	Reactor		Remark
			TCR	Specimen	
1	Nominal Voltage of system	kv	33	-	
2	Nominal current	A	1313	2000	
3	Number of layers with same current	N	7	2	
4	Number of turn in any layer	n	75	4	
5	Number of set	quantity	2	1	
6	Shape of coil	-	Cylindrical	Cylindrical	
7	Section of conductor	mm^2	620	500	
8	Material	-	Aluminum	Aluminum	
9	Outer Radius	mm	1850	580	
10	inner Radius	mm	1550	525	
11	Weight	kg	5850	500	
12	Total height	mm	5300	-	
13	Distances from top of foundation	mm	2000	-	
14	Manufacture's co.	-	TRENCH	ABB	
15	Magnetic Clearance	mm	=2*2244	-	Outer Radius
16	Magnetic Clearance	mm	=2*2380	-	Height from outer edge

Table 4: Properties of material use in simulation

Item	Properties	Unit	Material		
			Normal concrete	Structural steel	Air
1	Density	kg/m^3	2300	7850	-
2	Coefficient of Thermal	$1/^0C$	0.000014	0.000012	-
3	Initial Temperature	^0C	52	52	52
4	Young's Modulus	P_a		$2E^{+11}$	-
5	Poisson's Ratio	-	0.2	0.3	-
6	Bulk Modulus	P_a	-	$1.667E^{+11}$	-
7	Shear Modulus	P_a	-	$7.692E^{+10}$	-
8	Heat Transfer Coefficient	$w/m^2\ ^0C$	-	-	10
9	Thermal Conductivity	$w/m\ ^0C$	0.72	60.5	-
10	Tensile Strength yield	MP_a	3	250	-
11	Tensile Strength ultimate	MP_a	4	460	-
12	Relative Permeability	-	1	5000	1
13	Bulk Conductivity	s/m	0.01	1500000	-

2.7 Steps to simulate and analyze

ANSYS is the very powerful software that manages all the simulation processes from start to finish. In addition, in this software, complex physical analysis is simplified.

2.8 Modeling, Electromagnetic Analysis and Calculation of Heat loses in Rebars

The purpose of this simulation and magnetic analysis is to obtain the power losses in the steel rebar mesh for use in thermal and mechanical analyzes. The heat power in the rebar is due to the amount of electric losses lost in it, or the ohm losses. By obtaining ohm losses over the entire rebar mesh, the temperature distribution in the foundation is determined. According to Table 3, for having physical and quantitative characteristics of the TCR, magnetic modeling was done. To begin the modeling, the geometry of the main reactor components, including the windings and its concrete foundation, must first be created. Foundation geometry consists of a concrete cube of 4000*4000*4000 mm. The rebar includes two symmetrical meshes with a diameter of 16 mm and a space of 200 mm. The concrete cover around rebars is 100 mm. The reason for inserting a100 mm coverage in the analysis is to consider the worst transfer conditions from the inside of the foundation to the outside. In other words, with a high concrete coverage, heat transfer from the inside to the outside of the foundation is less and the temperature inside the rebar can be increased more. Figure 4 shows the magnetic model of the reactor, and Figure 5 illustrates its magnetic simulation.

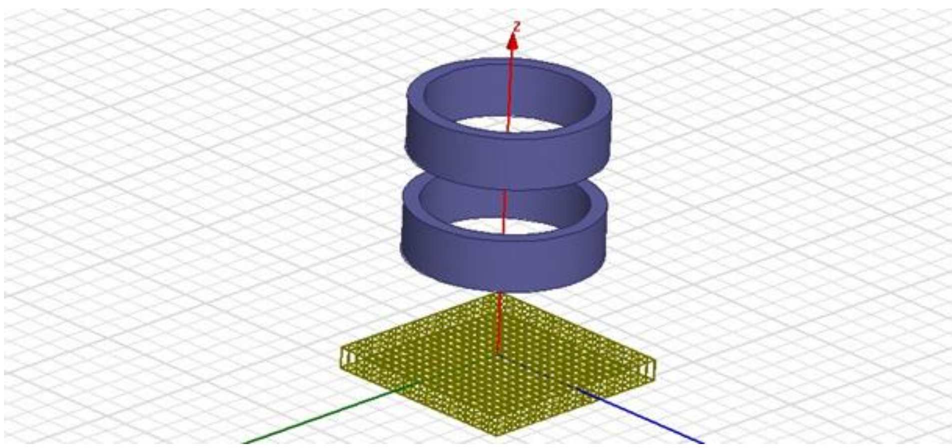

Figure 4: Magnetic model of TCR and RC rebars

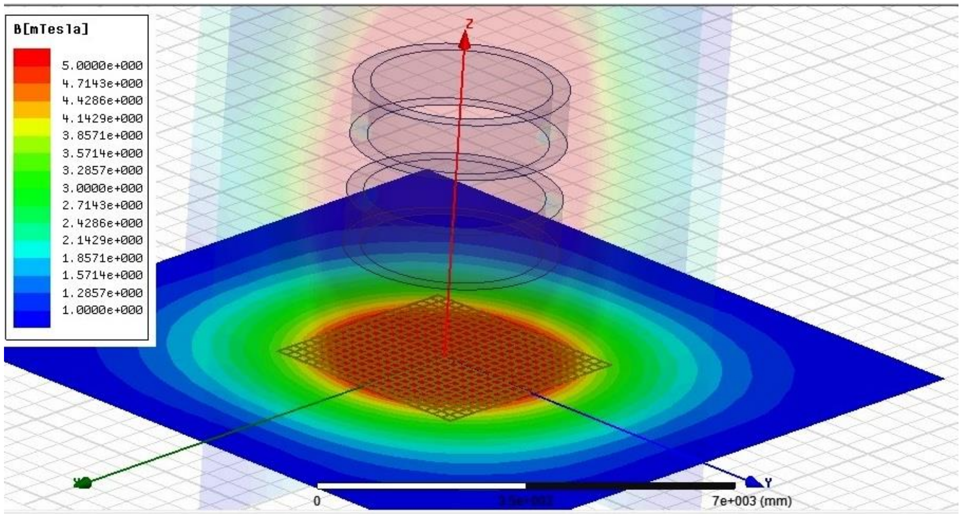

Figure 5: Magnetic field contour line around TCR and top of foundation

2.9 Electricity losses

The Ohm losses are due to the electric current passing through the conductor (here the steel rebars), which is proportional to the second power of the current and the electrical resistance of the flow path. In this simulation, ANSYS calculates the sum of the ohm losses and eddy losses. Table 5 shows the losses in steel rebars with the assumption of the electrical connection between the rebars and the insulating state of the intersection of the rebars. Compared to table 5, the losses in the insulation state of the rebars are approximately zero.

Table 5: Electrical losses in TCR foundation rebars based on distance between bottom of reactor and top of rebars (H)

Item	Unit	Electrical insulation parts in cross points of rebars in H=2000 mm	
		Without insulation	With insulation
Total losses	watt	≈ 20055	≈ 0.5

2.10 Modeling of Steady state thermal

Tohidi (2013) states when heat transfer is considered constant when the heat flow does not change with time, and if the temperature does not change with time, the temperature of the system and the thermal loads on the system do not change with time. From the first law of thermodynamics, the stable thermal equilibrium can be expressed simply. According to Equation (4) for energy conservation, it is necessary that the pure energy changes of a system are always equal to the transfer of pure energy from the system's boundaries to heat or operation.

$$\text{Energy Output} + \text{Energy Input} = 0 \quad (4)$$

Thermal stability tool has been used to calculate the heat exchange from the rebar and concrete mesh with its analysis environment and its amount. The purpose of the thermal analysis is to determine how much heat generated in the steel rebar loop is transmitted out through the conduction of the concrete body and the displacement of the contact surface of the concrete into the air and the temperature of the rebar with the assumption of the initial values and considering the properties of materials used in reinforced concrete, how much can it increase?

2.11 Applying of initial and boundary conditions

At this stage, the initial conditions and boundary conditions are applied. In order to enter the magnetic field into the thermal model, it must first connect the magnetic and thermal analysis module in the main software environment. One of the most important steps in this case is the definition and determination of the heat transfer from the external surfaces of the concrete. It is assumed here that all the exterior surfaces of the concrete are exposed to air and the ambient temperature is assumed 52 °C. Various sources of air displacement coefficient range from 10 to 100 watts per square meter for one degree of centigrade. In this analysis, the air displacement coefficient of 10 watts per square meter was considered to be one centigrade, which is the most common mode. Other required coefficients are applied by the software.

2.12 Thermal Analysis Results

In the solution, the required answers for the software are specified. Here the temperature and lines with the same temperature in the RC are required. According to Figure 6, the most important output parameter is the thermal analysis of temperature at different points and lines with the same temperature throughout the object. In the steady state, the heat source has an energy exchange environment eventually reach the temperature equilibrium.

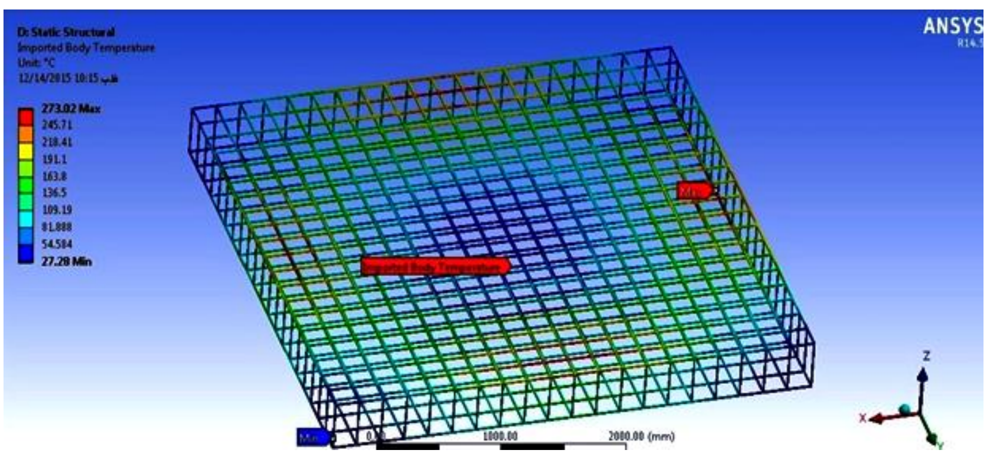

Figure 6: Contour of temperature in rebar mesh

The distribution of temperature in the upper and lower mesh and the whole mesh is not uniform and the temperature gradient at the side of the rebars is more than the center and its corners. According to the results of the analysis, assuming a temperature of 52 °C and a steady heat transfer, the maximum temperature on the surface of the rebar may reach about 300 °C. This temperature and its distribution are used in mechanical analysis.

2.13 Mechanical analysis

Finally, the mechanical and structural behavior of concrete foundation has been analyzed with the help of Static Structural tool in ANSYS. The purpose of this part of the simulation is to answer the question as to whether the mechanical effects caused by the heat generated in the rebars can cause the RC to fail or not. To this end, based on the simulation results and comparison with the criteria derived from the second part, the threshold of failure and concrete fracture was determined and based on permitted tolerances and acceptable criteria were defined and judged. The deformation levels of the concrete section of the TCR foundation and the shape of the rebar mesh are shown in Figures 7 and 8, respectively. Figure 9 shows the safety coefficients obtained from the mechanical analysis.

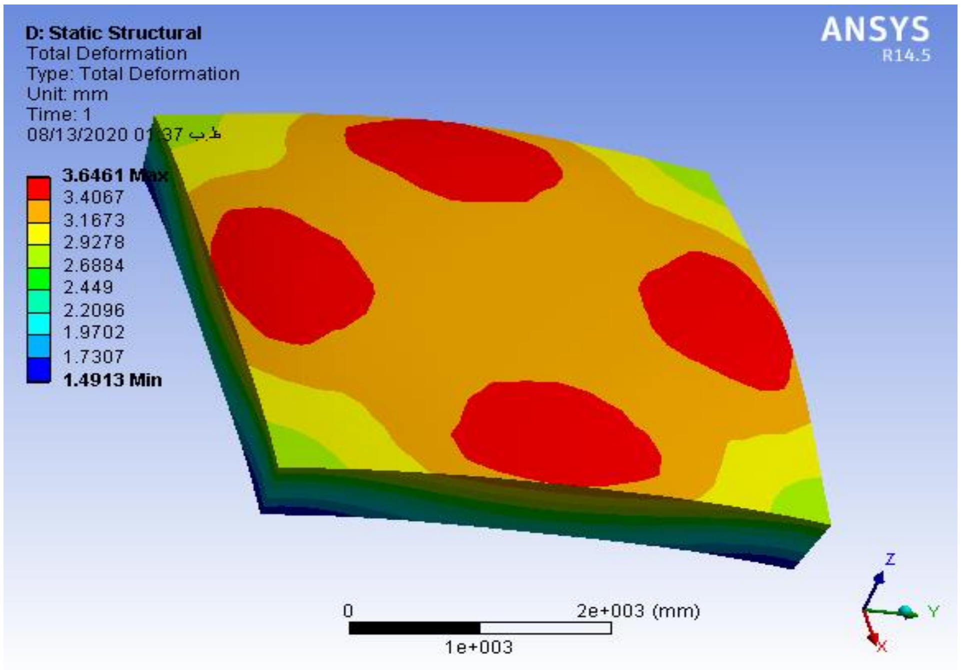

Figure 7: TCR concrete deformation curve

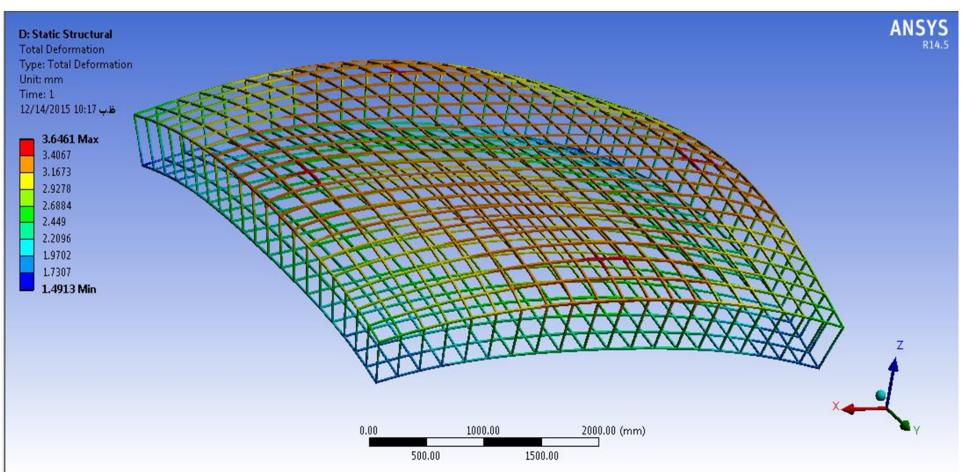

Figure 8: Rebar deformation of TCR foundation

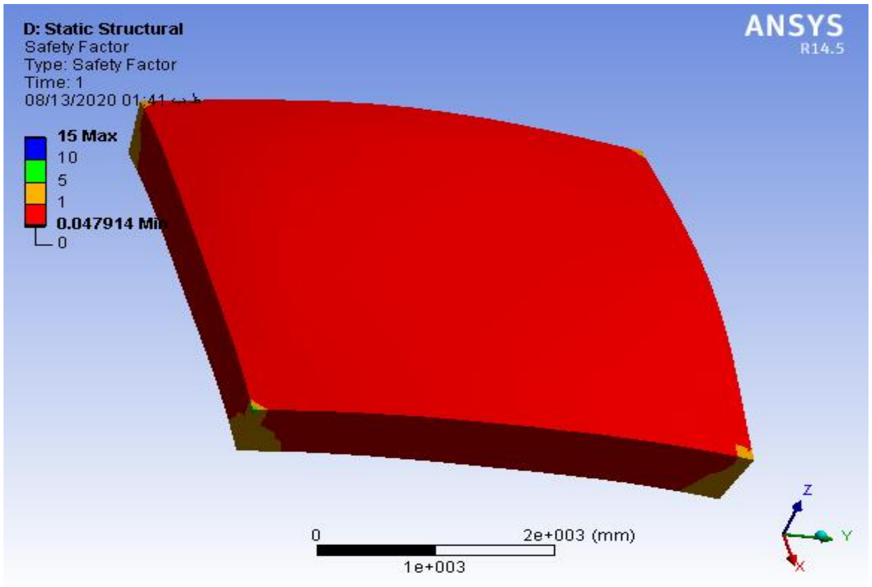

Figure 9: Safety coefficients less than unit

In order to investigate the failure of the TCR foundation, safety tools and software failure criteria have been used. If the coefficient of confidence is less than one unit, the failure conditions are provided. Simulation and analysis for H distance with the values of 1000, 2000, 3000, 4000, 4500 and 5000 mm were repeated. The reason for this was to find a distance and say that the effects of the magnetic field on the foundation is low and causes the failure of concrete. Table 6 shows the results of six stages of model analysis for different distances.

Table 6: Variation of power losses, maximum temperature, maximum deformation of structure and safety coefficient based on H distance

Item	Factor	unit	H (mm) in 52°C ambient temperature					
			Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
			1000	2000	3000	4000	4500	5000
1	Losses	w	100000	20055	5070	1410	766	424
2	Maximum temperature in rebar	°C	1270	300	113	69	61	57
3	Maximum deformation of structure	mm	20.386	3.7	0.838	0.219	0.116	0.063
4	Safety coefficient	-	0.0079	0.038	0.159	0.57	1.06	1.9

Based on the results and outputs of the software and the mechanical analysis, if there is no attempt to remove the effects of the magnetic field, the foundation may be failed. Table 6 also shows that if the foundation is designed with the magnetic field and implemented with normal rebars, the distance H should be at least 4.5 meters.

3. Results and Discussion

Based on the results of the practical test of the sample reactor and the simulation results (Table 6) if the reinforcement is carried out in the usual manner, the electrical connection of the reinforcement, at a distance of 2000 mm, the power dissipated to the extent that the safety factor is less than the unit value due to the failure criteria of the software, the conditions for concrete failure are provided. Based on table 6, the minimum distance H should be more than 4500 mm, and in the Technical documentation of the permissible magnetic permeability device for the TCR is equal to 4960 millimeters (Katiyar et al., 2022). The electrical and thermal ventilation of the reactor must be observed. The values of the Ohm losses of the rebars, the maximum temperature, the maximum variation and the coefficient of safety are given in terms of different H. Figures 10-12 show, respectively, the power losses, the maximum temperature in the rebar mesh and the safety coefficient in H, respectively.

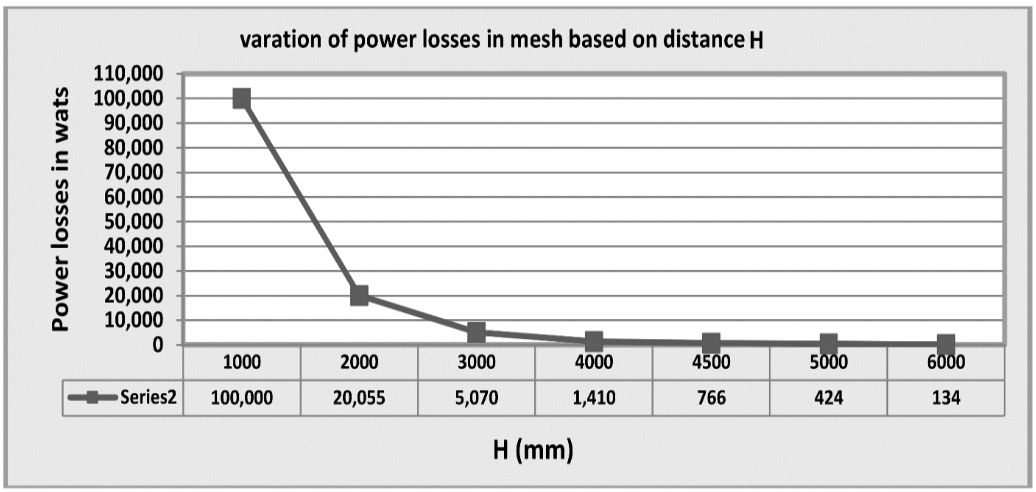

Figure 10: Changing of losses in accordance H distance

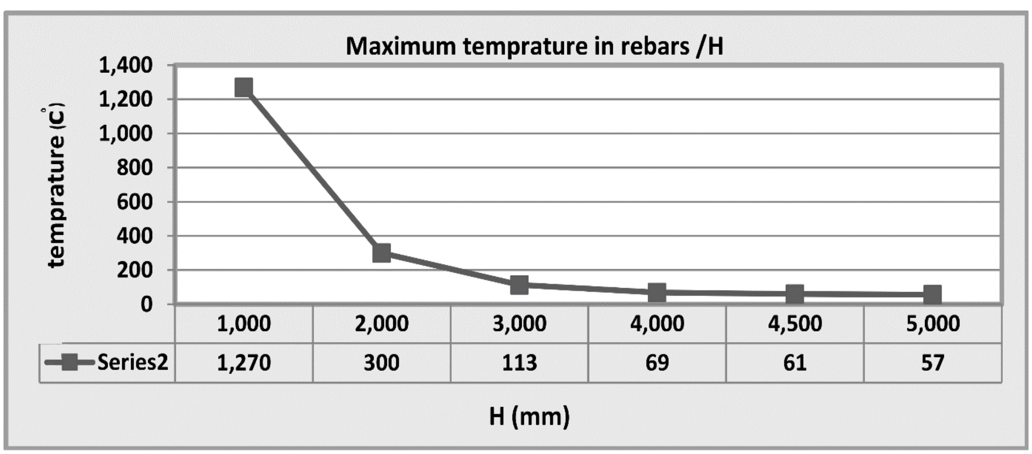

Figure 11: Changing of maximum temperature in accordance H distance

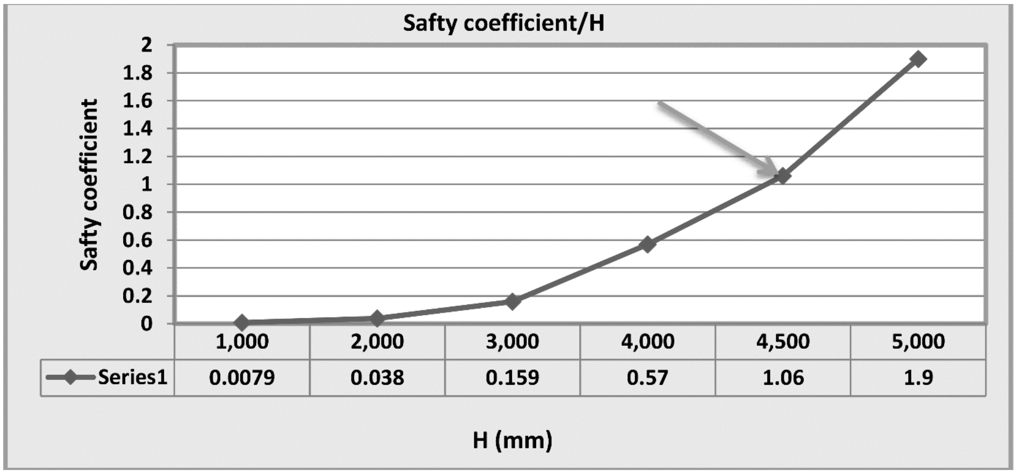

Figure 12: Changing of safety coefficient in accordance H distance

According to the above-mentioned articles, to reduce or eliminate the adverse effects of high-magnetic devices, such as a dry-type reactor, it is necessary to apply some solutions to minimize these effects. According to the studies conducted, the most important of these measures include the following.

a-The use of non-magnetic steel reinforcements of type 304: the use of non-magnetic metallic materials, such as 304 steel rebar, and insulating the joints of rebars to prevent the formation of a metal loop, is technically recommended by manufacturers. There are limitations in the application of this method, including the fact that steel rebars have a smooth surface and are not allowed to be used as main rebars [8]. In addition, they are much more expensive than conventional rebars. In this case, the reactor magnetic field must be prevented from forming a metal loop. In either case, all parts of the retaining structure should be made of non-metallic materials or non-magnetic metals in order to minimize their losses and, as far as possible, increase the spacing of the electric reactor to the foundation by increasing the length of the retaining post leg made of suitable materials.

b- Using Fiber Reinforcement Polymers: Using FRP rebars instead of conventional rebars is another solution that, if any, can be used as a suitable replacement for a conventional rebar in the market. In addition to the problem of preparing it at site and at high prices, their bending should be done in the manufacturing factory, which is not desirable and may create problems for the project. In this case, the problem of magnetic effects will be eliminated completely and corrosion problems will also be eliminated. In terms of corrosion, it is a good option to use FRP, but in practice, the experience of Iranian designers and operators in this area is low, which increases the risk of the project and, despite the relative advantages, is not a suitable method for implementing the concrete foundation of the reactor.

c- Using conventional rebars: Using a conventional rebar, as well as insulating the joints and extending the lengths of the equipment bases as far as possible, can be a good way to implement the foundation of the TCR. In this case, for building the foundation of the reactor, ordinary rebars are used, and only the contact points of the rebars are insulated with polyvinyl chloride materials. If the electrical and ventilation issues of the TCR ventilation are used, this method is much more convenient and economical in terms of material preparation and performance. The use of a conventional rebar to construct the foundation of an air type electrical reactor by insulating the contact points of the rebars is a suitable option and can be used. This method is feasible and worked for electrical reactor foundation (Figure 13).

Figure 10: Procedure to insulate the intersection of reinforcement with insulating materials

d- Use of fiber concrete: According to the performance of the Foundation, it is not permitted to implement non-reinforced concrete [ABA 2009] , but the Ministry of Energy Standard has permitted the use of non-reinforced concrete for weight less than 5 tons (Ministry of Energy 2009). In this case, polypropylene fiber is recommended to increase the tensile and flexural strength of concrete.

3.1 Construction time of the TCR foundation

Except for the case of using FRP rebar, in three other methods, construction times are equal to a good approximation, but if using the FRP rebar, the time of the order of the materials, which is about 3 months, should be added to the project time. This will increase the cost of foundation establishment.

3.2 Use of conventional rebar with additional arrangements

Methods for implementing the TCR foundation, taking into account cost, time and quality factors and for different constructional conditions are presented in Table 7. Based on table 7 the use of conventional rebars with technical and economic issues and the insulation of their contact points is a feasible and acceptable solution. It is easy to design and perform, and the required human resources are available. This method has a weakness despite the many benefits it has. One is that the use of plastic materials in concrete may have a negative effect on concrete loading and concrete durability, and the rebar is exposed to a low frequency magnetic field that may exacerbate the corrosion process of the rebars. The corrosion of the reinforcement requires separate study, but by making appropriate concrete with a low permeability and increasing the concrete cover, the corrosion concerns of the rebar can be delayed.

Table 7: Methods of Establishment TCR foundation

Item	Title	Technical	Economical	Duration	Ease of preparation of materials	Ease of implementation	Remark
1	Use of steel type 304 rebar	Well, its main advantage is non-magnetism and is more resistant to corrosion.	It is not suitable because the price of the 304 rebar is about 14 times higher than the conventional rebar.	Suitable	Easy- time to order and make them a little more than ordinary reinforcem ent	easy	should not be used as the main reinforcement in the structure
2	Use of FRP rebar	Well, it is non-magnetic and does not have corrosion problems.	It is not suitable because the price of the FRP rebar is about 15 times higher than the conventional bar.	High- Increase run-time due to long ordering and purchase times and longer reinforcemen t	Hard - not produced inside the country.	Hard - There is not enough experience in design and implementation	It is technically good, but not for other items. The ordering time is about 3 months and there are problems with the implementation. Bending of reinforcement is carried out at the factory.
3	Use of conventional rebar + Additional arrangement (insulating the rebars electrically and optimizing the clearance)	Suitable	Suitable	Suitable	easy	easy	It is convenient and inexpensive.
4	Use of fiber concrete	Allowed only For reactors weighing less than 5 tons. NO Corrosion and magnetic problems.	relatively Suitable	Low - Remove reinforcemen t Time	easy	easy	Well - but not everywhere useful and not .recommended

4 Conclusion

In this research, the magnetic field of the TCR was simulated and analyzed using ANSYS. Then, the mechanical stresses of its RC foundation were compared with the scientific criteria of failure of materials. Then, four methods for constructing the foundations of the reactor under study were evaluated with time, cost, and quality criteria. Results obtained from comparison between methods carried out in this study are as follow.

1- According to the results of the experimental test of the reactor and the results of the simulation of the TCR, the magnetic field of the reactor induces voltage and creates the current in the steel reinforcement closed loops.

2- Rotary and eddy current create heat in steel rebars.

3-The results of the simulation of the TCR showed that the losses caused by the rebars in two cases of insulation of the contact points of the steel rebars are very low and can be neglected, but when the contact points do not insulate, the losses are very high.

4- The heat generated by current can cause failure in concrete, especially at the external surface.

5- If the concrete structure of the TCR is designed and implemented without any consideration regarding the effect of the magnetic field and in conventional methods with steel rebars, concrete failure can occur.

6- Concrete failure may be in the form of a crack, which increases the permeability and reduces the durability of concrete.

7- It is imperative to observe the electrical and thermal limits for the construction of the reactor. If using insulating method, the rebar contacting points and neutralizing the thermal effects of the magnetic field, the reactor's distance to the foundation can be reduced to the limits specified for the electric field and the thermal ventilation of the device.

8- If no action is taken to remove or reduce the effects of the reactor's magnetic field, the resulting loss will result in energy waste.

9- The presence of electrical losses in the rebars will also change the electrical characteristics of the reactor.

10- The use of conventional rebars in the reinforced concrete foundation of the reactor, with insulating connecting points, causes electrical and thermal protection (the required time for ventilation and cooling of the reactor) in terms of cost, time and quality.

11- Any form of closed metal loops in steel rebars should be avoided in as far as possible.

In general, all parts of the holding structure should be made of non-metallic materials or non-magnetic metals in order to minimize the losses they cause. In addition to observing the magnetic limits recommended by reactor makers and similar equipment with high magnetic field, the calculations and results of magnetic simulations should also be collected and carefully examined.

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