Форма № 24

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ

Національний університет «Запорізька політехніка»

Фізико-технічний інститут, Електротехнічний факультет
(повне найменування інституту, факультету)

Електричні та електронні апарати
(повне найменування кафедри)

Пояснювальна записка

до дипломного проєкту (роботи)

___________________бакалавр___________________
(ступінь вищої освіти)

на тему: Комутаційний апарат для загальнопромислових стаціонарних установок, 110 В, 110 А.

Виконав: студент(ка) 4 курсу, групи Е-417а

Спеціальності 141 Електроенергетика, електро-
___техніка та електромеханіка__
(код і найменування спеціальності)

Освітня програма (спеціалізація)
______Електричні та електронні апарати_______
_______________Маслов Д.П.__________________
(прізвище та ініціали)

Керівник _______Жорняк Л.Б._________________
(прізвище та ініціали)

Рецензент______Сергієнко В.С._______________
(прізвище та ініціали)

2021

Форма № 25

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
Національний університет «Запорізька політехніка»
(повне найменування закладу вищої освіти)

Інститут, факультет___Фізико-технічний інститут, Електротехнічний факультет__
Кафедра______________Електричних та електронних апаратів_________________
Ступінь вищої освіти ___________________бакалавр_________________________
Спеціальність ____141 Електроенергетика, електротехніка та електромеханіка____
(код і найменування)
Освітня програма (спеціалізація)_____Електричні та електронні апарати_______
(назва освітньої програми (спеціалізації)

ЗАТВЕРДЖУЮ
Завідувач кафедри __Андрієнко П.Д.__
____
«_______» ________________20___року

З А В Д А Н Н Я
НА ДИПЛОМНИЙ ПРОЄКТ (РОБОТУ) СТУДЕНТА(КИ)

________________________Маслова________________________________Дмитра Павловича_______________________
(прізвище, ім'я, по батькові)

1. Тема проєкту (роботи)__Комутаційний апарат для загальнопромислових стаціонарних установок 110 В, 110 А_________________________________

керівник проєкту (роботи)______ Жорняк Людмила Борисівна кандидат технічних наук, доцент____
(прізвище, ім'я, по батькові, науковий ступінь, вчене звання)

затверджені наказом закладу вищої освіти від «_____»__________20__року №___

2. Строк подання студентом проєкту (роботи)________________________________

3. Вихідні дані до проєкту (роботи)_Номінальна напруга 110В, номінальний струм
110А____
____
____

4. Зміст розрахунково-пояснювальної записки (перелік питань, які потрібно розробити)_Огляд існуючих конструкцій, Розробка елементів керування, Система дугогасіння, Розробка механізму аппарату, Розробка електромагнітного приводу, Розробка дизайну аппарату____
____

5. Перелік графічного матеріалу (з точним зазначенням обов'язкових креслень)
1 Збірне креслення контактору постійного струму; 2 Головні контакти; ________
3 Електромагнітний привід;____

4 Дугогасильна камера, 5 Монтажна скоба

6. Консультанти розділів проєкту (роботи)

Розділ	Прізвище, ініціали та посада Консультанта	Підпис, дата	
		завдання видав	Прийняв виконане завдання
Економіка	Пожуєва Т.О., професор		
Охорона праці	Скуйбіда О.Л., доцент		

7. Дата видачі завдання «______» ________________20___року.

КАЛЕНДАРНИЙ ПЛАН

№ з/п	Назва етапів дипломного проєкту (роботи)	Строк виконання етапів проєкту (роботи)	Примітка
1	Техніко-економічне обгрунтування проєкту	19.04.2021	
2	Попередній розрахунок головних елементів апарата	26.04.2021	
3	Повірний розрахунок з висновками про роботоспроможність елементів апарата	30.04.2021	
4	Розрахунок економічної ефективності проєкту	05.05.2021	
5	Розробка заходів з охорони праці	07.05.2021	
6	Виконання загального виду виробу, робочих креслень головних вузлів та деталей апарата	10.05.2021	
7	Оформлення розрахунково-пояснювальної записки проєкту	14.05.2021	
8	Узгодження проєкту з керівником проєкту та консультантами з економіки та з охорони праці	17.05.2021	
9	Нормоконтроль та затвердження завідувачем кафедри	19.05.2021	
10	Рецензування проєкту	27.05.2021	
11	Захист проєкту	27.05.2021	

Студент(ка) ____________ ______**Маслов Д.П.**___

(підпис)	(прізвище та ініціали)

Керівник проєкту (роботи) ______________ ______Жорняк Л.Б.__

(підпис)	(прізвище та ініціали)

ABSTRACT

EN: 70 pages, 11 figures, 16 tables, 44 sources.

SWITCHING DEVICE, DIRECT CURRENT, CURRENT, CONTACTOR, VOLTAGE, ELECTROMAGNETIC, SWITCHING, ELECTROMAGNET, CURRENT CIRCUIT, ELECTRIC APPARATUSES, ELECTROMAGNETIC DRIVE, CONTACTS.

The object of the study - is a switching device for general industrial stationary plants (KPV-604DC contactor).

The aim of the course project was to develop a DC contactor for specified nominal parameters, the possibility of electrical apparatuses design determination based on the calculation models data when we compare the calculated values with the parameters of the prototype. [6]

The research method is based on the electromagnetic switching relays and contactors calculation method that was offered by Taev I.S.[12]

Contactor – is a switching device with non-manual control, used for switching, conducting and disconnecting currents under normal circuit conditions, including long-term overloads. Contactors where closing received the greatest distribution and opening is carried out under the influence of an electromagnetic drive. High efficiency of such devices and simple design predetermined their wide distribution, and, consequently, the need for their mass production.

CONTENT

INTRODUCTION

Contactor – is an electrically controlled switch that is used for switching an electrical power circuit, similar to a relay except with higher current ratings and a few other differences. A contactor is controlled by a circuit, with much lower power level than the switched circuit.

The most widely are used single- and double-pole DC contactors and three-pole AC contactors. The mechanical and electrical wear resistance requirements for contactors are increased due to frequent switching (the number of on-off cycles for contactors of different categories varies from 30 to 3600 per hour),. The contactors for both AC and DC contain: an electromagnetic system, a contact system consisting of movable and fixed contacts, an arc-extinguishing system, a system of block contacts (auxiliary contacts, switching signaling and control circuits for the contactors operation). Unlike automatic switches, contactors can only switch rated currents, they are not designed for disabling short-circuit currents.

The basic requirements for DC contactors:

- the prolonged operation possibility at a high cut-off frequency;
- mechanical wear resistance;
-high breaking and switching capacity;
-technical design;
-small weight and compact dimensions.

Electromagnetic contactor is an electrical apparatus that is intended for power electrical circuits switching. Short-circuiting or opening of contacts of the contactor is carried out more often with the help of an electromagnetic drive.

General industrial contactors are classified in the following way:

- by the current of the main circuit, the control circuit current, the switching coil (DC, AC, DC and AC);
- by the number of main poles (from 1 to 5);

- by the rated current of the main circuit (from 1.5 to 4800 A);
- according to the rated voltage of the main circuit (from 27 to 2000 V DC, 110 to 1600 V AC with frequency 50, 60, 500, 1000, 2400, 8000, 10 000 Hz);
- by the switching coil rated voltage (12 to 440 VDC, 12 to 660 V AC 50 Hz, 24 to 660 V AC 60 Hz);
- by the presence of auxiliary contacts (with contacts, without contacts).

The contactors also differ in the nature of the main circuit conductor connection and the control circuit, the mounting method, the type of external conductors connection.

Normal operation of contactors is allowed if:

- the voltage at the terminals of the main circuit to 1.1 and the control circuit from 0.85 to 1.1 of the rated voltage of the respective circuits;
- the AC voltage drops to 0.7 of the rated voltage, the coil must keep the armature of the contactor electromagnet in fully pulled position and do not hold it when removing the voltage.

The series of electromagnetic contactors manufactured by the industry are designed for use in different climatic zones, work under different conditions determined by the location in operation, mechanical influences and explosiveness of the environment and, as a rule, do not have special protection against touch and external influences.

1 EXISTING DESIGNS OVERVIEW

1.1 KPD – 110 Contactor

KPD-110 series contactors are designed for DC circuits switching of crane and traction electrical equipment with voltage up to 220V and alternating current of crane equipment with voltage up to 440V with a frequency of 50 and 60 Hz with the switching coils supplied with a constant voltage up to 220V .

Contactors are used in the following modes:

- Repeatedly short-term;
- intermittent-continuous;
- continuous;

Contactors 114 are allowed to be used in areas with a temperate and cold climate.

Figure 1.1 – KPV-600 Contactor dimensions

1.2 KPV – 600 Contactor

The contactor allows the DC motor to be switched on, the motor must be switched off directly, and the power plant decelerates counter-current.

The operation of the contactor is very diverse and allowed in severe conditions. In this case, the main contact pair must meet the requirements of reliability and manufacturability.

Contactors of the KPV600 series with infrequent trips (up to 30 starts per hour, for example, in generator-motor systems) of the 2nd and 3rd values are suitable for operation at voltages up to 440 V, contactors 4 and 5-th magnitude at a voltage of up to 600 V DC.

The retractor coils of the contactors are suitable for operation only from the DC network and have a rated voltage of 24, 48, 110 and 220 V.

By heating, the retracting coils withstand a voltage of up to 105% from the nominal value.

The contactors can operate with voltages at the retractor coil terminals from 0.85 to 1.1 and the main circuit from 0.1 to 1.1 of the respective circuits nominal voltage.

Contactors with closed main contacts allow the switching frequency to be 1200 inclusions per hour, with breaking contacts up to 150 inclusions per hour.

The contactors are suitable for operation in continuous, intermittent-continuous, short-time, short-time operation modes. Work of contactors at rated current in continuous mode, i.e. In the mode where the contactor does not turn off for 8 hours or more, it is permissible in case when the contact surfaces of the contacts are made of silver (contacts with silver inserts).

Figure 1.2 – Contactor KPV-600

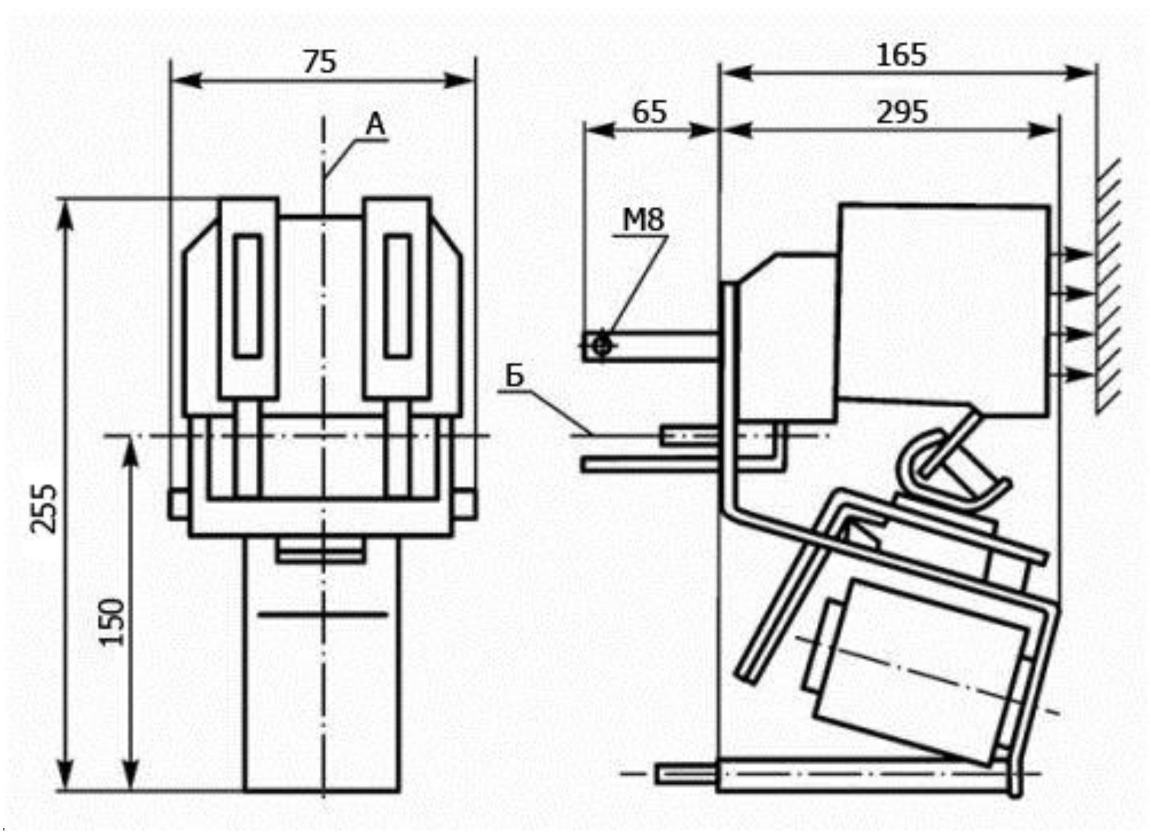

Figure 1.3 – KPV-600 Contactor dimensions

1.3 Sirius SIEMENS 3RT1064 – 6AP36 Contactor

The contactor is designed for motors switching. Power is 110 kW, current is 225 A. It is resistant to climatic influences, it is safe to touch. Contactors can be equipped with RC-links, varistors, diodes, combinations of diodes in order to limit overvoltage's in the coil, when they are disconnected. There is a wide range of variable and constant control voltages.

Figure 1.4 – Sirius SIEMENS 3RT1064-6AR36 Contactor

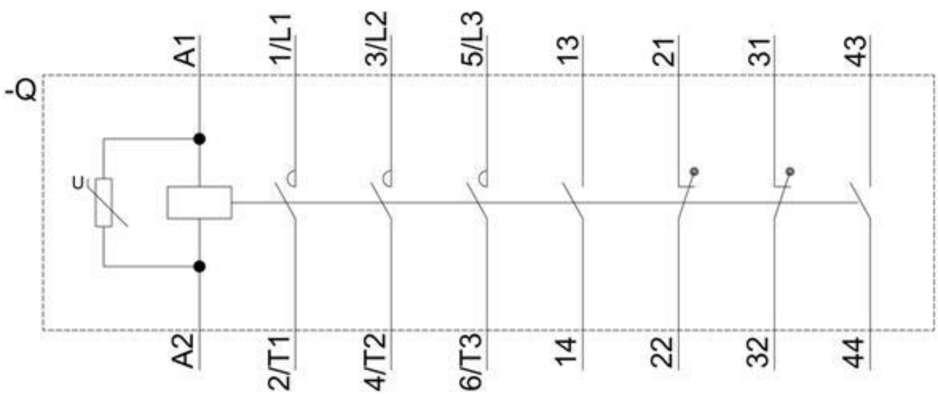

Figure 1.6 –Sirius SIEMENS 3RT1064-6AR36 Contact sequence

2 CURRENT CONTROL ELEMENTS DESIGN

Since the contactor operates in a short-time mode, we determine the value of the equivalent long-time current flowing through its current-carrying parts, I_{eq} [6]:

$$I_{eq} = I_n \cdot \sqrt{\frac{DI\%}{100} + \frac{z}{600} \cdot \sqrt{\frac{DI\%}{100}}} \ , \tag{2.1}$$

where DI – is the duration of inclusion, equal to 40 %;

I_n – is the rated contactor current, equal to 250 A;

z – is the inclusion rate per hour, equal to 1200.

$$I_{eq} = 250\text{Ч}\sqrt{\frac{40}{100} + \frac{1200}{600}\text{Ч}\sqrt{\frac{40}{100}}} = 322{,}5 \ \ \text{A}$$

As $I_{eq}>I_n$, we calculate the equivalent current in the circuit.

2.1 Determination of the bus cross-section area

To determine the current-carrying parts cross-section, we choose copper as the material of current-carrying parts, and the insulation parts correspond to the heat resistance class. The permissible heating temperature for continuous operation T_{all}=105 ^{o}C.

$$a \cdot b \cdot (a+b) = \frac{I^2{}_{eq} \cdot \rho_0 \cdot (1 + \alpha \cdot T_{all})}{2 \cdot K_T \cdot (T_{all} - T_{amb})} \ , \tag{2.2}$$

where ρ_0 – is a specific electrical resistance equal to 1,75*10^{-6} Ohm·cm;

α– is the temperature coefficient of resistance equal to 0,004 1/˚C;

T_{amb} – is the ambient temperature equal to 40 ˚C [7];

T_{all} – is the conductor heating permissible temperature, equal to 105 ˚C;

K_{ht} – is the heat transfer coefficient, equal to $6 \cdot 10^{-4}$ Vt/cm^2 deg.

$$a \cdot b \cdot (a+b) = \frac{(322,5)^2 \cdot 1,75 \cdot 10^{-6} \cdot (1+0,004 \cdot 105)}{2 \cdot 6 \cdot 10^{-4} \cdot (105-40)} = 3,3 cm^3$$

We take the bus bar width a = 0.5 cm, then b is found from the equation:

$$0,5 \cdot b^2 + 0,25 \cdot b - 3,3 = 0$$

$$b = 2,5\ cm.$$

Cross-sectional area:

$$S = a \cdot b \qquad (2.3)$$

$$S = 0,5 \cdot 2,5 = 1,25\ cm^2$$

Perimeter:

$$p = 2 \cdot (a+b) \qquad (2.4)$$

$$p = 2 \cdot (0,5+2,5) = 6 cm$$

2.2 Determination of the live parts heating area temperature

Heating temperature of current-carrying parts in nominal mode:

$$T_{amb} = T_{all} + \rho_0 \frac{I^2_{eq} \cdot (1+\alpha \cdot T_{all})}{K_{ht} \cdot S \cdot p} \qquad (2.5)$$

$$T_{amb} = 40 + \frac{(322,5)^2 \cdot 1,75 \cdot 10^{-6} \cdot (1+0,004 \cdot 105)}{6 \cdot 10^{-4} \cdot 1,25 \cdot 6} = 97^oC$$

The temperature of current-carrying parts heating is less than the permissible temperature, determined by the heat insulation resistance class.

In the short-circuit mode, we determine the thermal stability current at $t_{s.c.}$=1, 5, 10 s. The permissible heating temperature in the short-circuit mode is assumed to equal $T_{s.c.}$=250 ^{o}C [8].

The temperature of the conductor heating in continuous mode T_{amb} will be equal to the allowable heating temperature T_{amb}=T_{all}=105 ^{o}C.

$$I^2{}_{sc} \cdot t_{sc} = \frac{\gamma \cdot c \cdot S^2 \cdot \ln \dfrac{1+\alpha \cdot T_{sc}}{1+\alpha \cdot T_{all}}}{\rho_0 \cdot \alpha}, \quad (2.6)$$

Where γ – the density of the bus material is equal to 8,9 kg/cm^2(for copper conductors);

c – specific heat, equal to 0,39 J/(g·°C).

$$I^2{}_{sc} \cdot t_{sc} = \frac{8{,}9 \cdot 0{,}39 \cdot 1{,}5625 \cdot \ln \dfrac{1+0{,}004 \cdot 250}{1+0{,}004 \cdot 105}}{1{,}75 \cdot 10^{-6} \cdot 0{,}004} = 265{,}4 \cdot 10^6 A^2 \cdot s$$

For:

$t_{s.c.}$=1s - I^2_{sc}=16291 A;

$T_{s.c.}$=5s - I^2_{sc}=7285 A;

$T_{sc.}$=10s - I^2_{sc}=5151 A.

The time of thermal resistance should not be less than 5 s.

With a given current limit tripping current $I_{sh} = 10 \cdot I_n = 2500A$, thermal stability time $t_{s.c}$=42,5 s, that is higher than the recommended values.

2.3 Switching contacts calculation

From the quadratic equation (2.7), we determine the contact resistance of the contacts RK without taking into account the electric arc influence the on contact heating. Permissible heating temperature T_m=120 ^oC.

$$T_m - T_{cir} = \rho_0 \frac{I^2{}_{eq} \cdot (1+\alpha \cdot T_{all}) \cdot \rho_0}{K_{ht} \cdot S \cdot p} + \frac{R_K \cdot I^2{}_{eq}}{2 \cdot \sqrt{\lambda \cdot K_{ht} \cdot p \cdot S}} + \frac{R^2{}_K \cdot I^2{}_{eq}}{8 \cdot \lambda \cdot \rho_0 \cdot (1+\alpha \cdot T_m)} \quad (2.7)$$

$$\frac{(322.5)^2 \cdot (1+0.004 \cdot 105) \cdot 1.75 \cdot 10^{-6}}{6 \cdot 10^{-4} \cdot 1.25 \cdot 6} + \frac{R_K \cdot (322.5)^2}{2 \cdot \sqrt{3.26 \cdot 6 \cdot 10^{-4} \cdot 1.25 \cdot 6}} +$$

$$+ \frac{R^2{}_K \cdot (322.5)^2}{8 \cdot 3.26 \cdot 1.75 \cdot 10^{-6} \cdot (1+0.004 \cdot 120)} = 120 - 40 = 80^oC$$

From this equation we obtain:

R_K=4,52$\cdot$10^{-5} Ohm.

Definition of the pressing force in contacts F_K is based on the formula:

$$R_K \approx \frac{K_1 \cdot (1+\frac{2}{3} \cdot \alpha \cdot T_m)}{(0.102 \cdot F_K)^m} \quad (2.8)$$

$$F = \frac{0.00006 \cdot (1+\frac{2}{3} \cdot 0.004 \cdot 120)}{0.102 \cdot R}$$

$$F_K = \frac{0.000776}{4.52 \cdot 10^{-5}} = 16.8N = 1.72 kg / s$$

The specific contact pressure is determined by the following formula (2.9):

$$F_{sp} = \frac{F_k}{I_{eq}} \quad (2.9)$$

$$F = \frac{16.8}{322.5} = 0.05 N \big/ A$$

The calculated value is below the recommended value, so we take F_{sp}=0,07 N/A

$$F_k = F_{sp} \cdot I_{eq} \tag{2.10}$$

$$F_k = 0,07 \cdot 322,5 = 22.58N$$

$$R_K \approx \frac{0.00006 \cdot (1 + \frac{2}{3} \cdot 0.004 \cdot 120)}{0.102 \cdot 22.58} = 3.439 \cdot 10^{-5} Ohm$$

Contact heating temperature:

$$T_\kappa = T_c + \rho_0 \frac{I^2{}_{eq} \cdot (1 + \alpha \cdot T_{all}) \cdot \rho_0}{K_T \cdot S \cdot p} + \frac{R_K \cdot I^2{}_{eq}}{2 \cdot \sqrt{\lambda \cdot K_T \cdot p \cdot S}} + \frac{R^2{}_K \cdot I^2{}_{eq}}{8 \cdot \lambda \cdot \rho_0 \cdot (1 + \alpha \cdot T_m)} \tag{2.11}$$

$$T = 114,021 C$$

Let us estimate the electric arc influence on the apparatus contacts heating.

Arc burning duration t_a=0,02 s, voltage on the arc U_a=0,5 U_n=110 V, arc current I_a= I_n/2=125 A.

The proportion of power losses in current-carrying parts of the apparatus, P_d:

$$P_d = \frac{0.1 \cdot U_a \cdot I_a \cdot t_a \cdot z}{3600} \tag{2.12}$$

$$P_d = \frac{0.1 \cdot 110 \cdot 125 \cdot 0.02 \cdot 1200}{3600} = 9.17 \text{ Wt.}$$

We substitute the obtained value of the power in (2.13):

$$T_K = T_c + \rho_0 \frac{I^2{}_{eq} \cdot (1 + \alpha \cdot T_{all}) \cdot \rho_0}{K_T \cdot S \cdot p} + \frac{R_K \cdot I^2{}_{eq} - P_d}{2 \cdot \sqrt{\lambda \cdot K_T \cdot p \cdot S}} + \frac{R^2{}_K \cdot I^2{}_{eq}}{8 \cdot \lambda \cdot \rho_0 \cdot (1 + \alpha \cdot T_m)} \quad (2.13)$$

From (2.13) we calculate the contact resistance of the contacts taking into account the thermal effect of the electric arc. The obtained value exceeds the previously obtained value R_k=3.439*10^{-5}Ohm. Contact force Fk that we took will provide the required contact resistance of the contacts.

Welding current I_{wc}:

$$I_{wc} \le k_2 \cdot \sqrt{F_k} \quad (2.14)$$

where k_2 – is an empirical coefficient equal to 1300 [7].

$$I_{wc} \le 1300 \cdot \sqrt{22.58} = 6177 A$$

I_{wc} > I_{off}, consequently, the contacts at this contact pressing force will not be welded.

The contact crushing site cross-section, S_0:

$$S_0 = \frac{F_k}{\Sigma_{sm}} \quad (2.15)$$

where Σ_{sm} – the buckling coefficient, that is equal to 30300.

$$S_0 = \frac{22,58}{30300} = 7,45 \cdot 10^{-4} sm^2$$

$$F = 2 \cdot 10 \cdot I \cdot \ln \frac{S}{S} \quad (2.16)$$

$$F_{ed} = 2 \cdot 10^{-7} \cdot 2500^2 \cdot \ln \frac{1.25}{7.45 \cdot 10^{-4}} = 9.3N$$

$F_{ed} < F_{к}$, consequently, the contacts will not diverge under the action of electrodynamic forces with a short circuit in the circuit.

2.4 Contact connections

Determination of the non-declutch bus-bus bolt connection transitional resistance.

The current-carrying buses material is copper.

I_{eq} = 117.243 A – is the equivalent current of contactor main circuit

J = 0.62 A/mm^2 – is the recommended current density value

Determination of the flexible connection technical parameters

$$a_{fc} = \frac{S_{fc}}{b_{fc} \cdot k_3}$$

$$\frac{24 \cdot 10^{-6}}{16 \cdot 10^{-3} \cdot 0.785} = 1.911 \cdot 10^{-3}$$

where $S_{fc} = 24 \cdot 10^{-6}$ – is the flexible connection of cross-sectional area surface;

$b_{fc} = 16 \cdot 10^{-3}$ – is the flexible connection width;

k_3 = 0.785 – is the coefficient.

Determination of the temperature of parts in the place of contact $T_к$:

$$T_к = T_c + \frac{I^2{}_э \cdot R_{ko}}{K_T \cdot S_k} \qquad (2.17)$$

Contacting surface area, S_1:

$$S_1 = \frac{I_{eq}}{j_m} \quad (2.18)$$

where j_m – is the current density, A/cm^2.

$$j_m = 0.31 - 1.05 \cdot 10^{-4}(I_{eq} - 200) \quad (2.19)$$

$$j_m = 0.31 - 1.05 \cdot 10^{-4}(322,5 - 200) = 0,2971 A / cm^2$$

$$S_1 = \frac{322,5}{0,2971} = 10,85 cm^2$$

when I_n=250 A, choose a steel bolt M10 [8].

Force of contact pressing, F_k:

$$F_k = f_k \cdot S_1 \quad (2.20)$$

$$F_k = 80 \cdot 10.85 = 868 kg = 8506 N$$

contact resistance of surfaces, $R_к$:

$$R_k = \frac{\varepsilon}{m_1 \cdot F^{m2}{}_k} \quad (2.21)$$

where ε – is the coefficient, , equals to 0,24·10^{-3}; depending on the contact surface material.

m_1 – is the number of bolts equals to 1;

m_2 – is the coefficient, equal to 0,7, depending on the number of contact points of contacts.

$$R_k = \frac{0.24 \cdot 10^{-3}}{1 \cdot 868^{0.7}} = 2.1 \cdot 10^{-6} Ohm$$

Ohmic resistance, $R_{k1:}$

$$\mathrm{R_{k1}} = k_c \cdot \frac{\rho \cdot l}{S} \quad (2.22)$$

where S – is the contact connection cross-sectional area, cm^2;

k_c– is the correction factor, determined by graph (figure 2.1);

l – is the contact connection length, cm;

ρ – is the material density, Ohm*cm

$$l = \frac{S_1}{b} \quad (2.23)$$

$$l = \frac{10.85}{2.5} 4.34 \ cm$$

For correction coefficient determination, we calculate the value l/a=4.34/0.5=8.68.

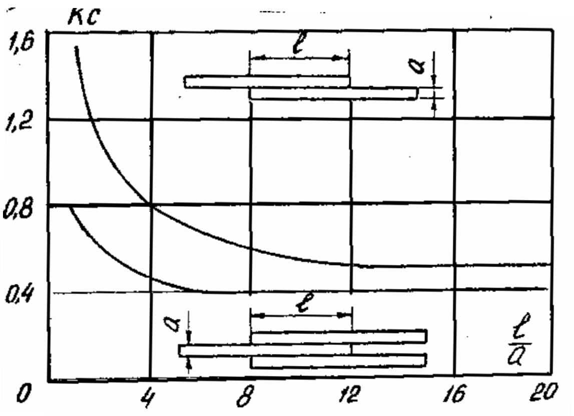

Figure 2.1 – Dependency graph K_c= f(l/a)

l=4.34, *a*=0.5

Figure 2.1 shows that the coefficient kc is equal to 0,6.

$$\rho = \rho_0 \cdot [1 + \alpha \cdot (T_{all} - T_c)] \tag{2.24}$$

$$\rho = 1.75 \cdot 10^{-6} \cdot [1 + 0.004 \cdot (105 - 40)] = 2.2 \cdot 10^{-6} Ohm \cdot cm$$

$$\mathrm{R}_{k1} = 0,6 \cdot \frac{2.2 \cdot 10^{-6} \cdot 4,34}{1.25} = 7,6 \cdot 10^{-6} Ohm$$

Total resistance of the contact connection, R_{ko}:

$$R_{ko} = R_k + R_{k1} \tag{2.25}$$

$$R_{ko} = 2,1 \cdot 10^{-6} + 7,6 \cdot 10^{-6} = 9,7 \cdot 10^{-6} Ohm$$

Full outer surface of the contact connection, S_k:

$$S = 2 \cdot (l \cdot b + 2 \cdot a \cdot l + a \cdot b) \tag{2.26}$$

$$S_k = 2 \cdot (4,34 \cdot 2,5 + 2 \cdot 0,5 \cdot 4,34 + 0,5 \cdot 2,5) = 32,88 \;\; cm^2$$

Excess temperature of the contact connection, τ_k:

$$\tau_k = \frac{I^2{}_э \cdot R_{ко}}{K_T \cdot S_к}, \tag{2.27}$$

$$\tau_k = \frac{322.5^2 \cdot 9.7 \cdot 10^{-6}}{6 \cdot 10^{-4} \cdot 32.88} = 51^oC.$$

Heating temperature, $T_{к1}$:

T_{k1}=40+51=91°C.

T_{k1}<T_k in nominal mode, therefore the contact connection of the specified dimensions is not a source of heat in the current-carrying circuit of the apparatus.

Determination of the contacts welding current in the short-circuit mode, $I_{пр}$:

$$I_{mp} = 2 \cdot \sqrt{\frac{\pi^{1/2} \cdot \lambda \cdot F_k \cdot (T_s - T_k)}{0,7 \cdot \rho \cdot \Sigma_{sm}}} \cdot \exp(\frac{0.4 \cdot c \cdot \gamma}{\lambda} \cdot \sqrt{\frac{F_k}{\pi \cdot \Sigma_{sm} \cdot t_{sc}}}) \qquad (2.28)$$

where T_{mp} – is the melting point that is equal to 1083°C.

$$I_{mp} = 2 \cdot \sqrt{\frac{3{,}14^{1/2} \cdot 3{,}9 \cdot 8506 \cdot (083 - 105)}{0{,}7 \cdot 2{,}2 \cdot 10^{-6} \cdot 30300}} \cdot \\ \cdot \exp(\frac{0.4 \cdot 0{,}39 \cdot 8{,}9}{3{,}9} \cdot \sqrt{\frac{8506}{3{,}14 \cdot 30300 \cdot 42{,}5}}) = 71333{,}4A \qquad (2.29)$$

The welding current is significantly higher than the breaking current (I_{off}=2500 A). It means that when the short-circuit current flows in the circuit, the contact connections are not welded.

3 ARCING SYSTEM

It is determined that the arc can be extinguished under given conditions without the use of special arcing devices (open break).

A free open fixed arc of direct current can be extinguished by a mechanical extension of its length to a critical value. Therefore, the contact gap must be equal to l_{kr}. The possible contact gap is tested when the critical current is extinguished .

$$l_{kr} = 0.42 \cdot 10^{-2} \cdot U_0 \cdot \sqrt{I_{kr}} \qquad (3.1)$$

where $I_{кr}$ – is the critical current of the contactor, equal to 10 A.

$$l_{kr} = 0.42 \cdot 10^{-2} \cdot 220 \cdot \sqrt{10} = 2,2cm$$

For an apparatus of this type, the contact gap β=2±2 cm

When $2 < l_{kp} < 10$ cm, the most expedient for this device is when the arc is quenched by movement and stretching under the action of electrodynamic forces.

Figure 3.1 shows the arc extinguishing condition for $I_{кr}$=10 A.

The calculation of DC arcing devices is carried out on the basis of the DC arc damping condition: the current – voltage characteristic of the arc must lie on the graph above the rheostatic characteristic of the circuit [2].

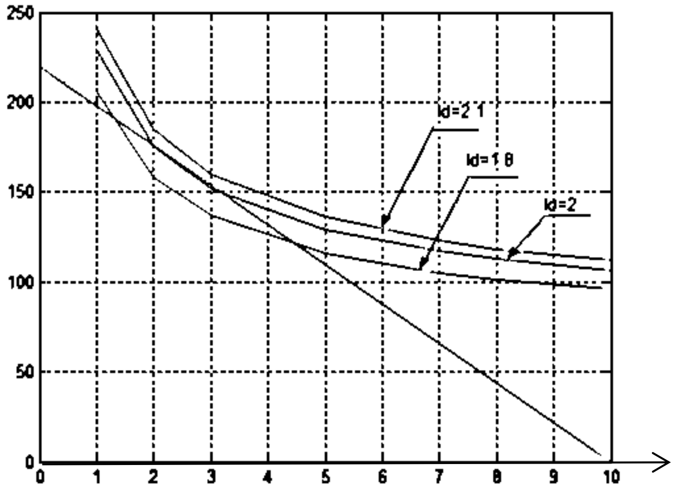

Figure 3.1- Arc extinguishing condition for $I_{кг}$=10 A

The geometric dimensions of the arc chute are determined by the arc length l_{kr} and the arc of the arc height h_a. The arc must not go beyond the arc chute. The shape of the arc on the contacts is represented as part of a circle built on the chord from the contact solution β [7].

The speed is determined by the empirical dependence, V_a:

$$Va = (6 + \delta_w)\sqrt{\frac{12,5 \cdot I \cdot N_w}{\delta_w}}\ , \qquad (3.2$$

where N_w – is field strength that is equal to 130 A/cm;

δ_w – is the slit width that is equal to 0,3 см.

Arc diameter, d:

$$d = 1.12\sqrt{\frac{I}{20 + V_a}} \qquad (3.3)$$

Stress gradient, E_s:

$$E_S \approx \frac{92}{\sqrt{I}} + \frac{0,312\sqrt{I}}{\delta_w^{2/3}} + 0,37 \cdot \sqrt[3]{\frac{V_a^2}{I}} \quad (3.4)$$

Arc voltage, U_a:

$$U_a = E_a \cdot l_a \quad (3.5)$$

The arc extinguishing time, that corresponds to an arc reaching the critical length $l_{кг}$.

$$t_a = \frac{\sqrt{l_{kr}^2 - \beta^2}}{3V_a} \quad (3.6)$$

For several current values in the range from 0 to I_n is under construction

The dependence $U_a = f(I_0)$, uses the successive approximations method.

Table 3.1 gives the values for plotting the rheostatic characteristic and CV arc at rated current 250 A.

Table 3.1 - Results of calculations for I_n=250 A

I_a, A	10	30	50	80	100	150	180	200	250
V_a,cm/s	466	540	279	147	637	679	221	557	331
d_a,cm	0,092	0,121	0,138	0,155	0,164	0,182	0,19	0,195	0,207
E_a,V	3,46	2,8	40	38,7	38,3	38,2	38,4	38,5	38,9
$U_{д}$ for l_a=4,5	240	192	180	174	172	171	172	173	175
U_a for l_a=4,6	245	196	184	177	176	175,7	176,5	177	179

Figure 3.2 shows the rheostatic and current-voltage characteristics of the arc at a nominal current of 250 A.

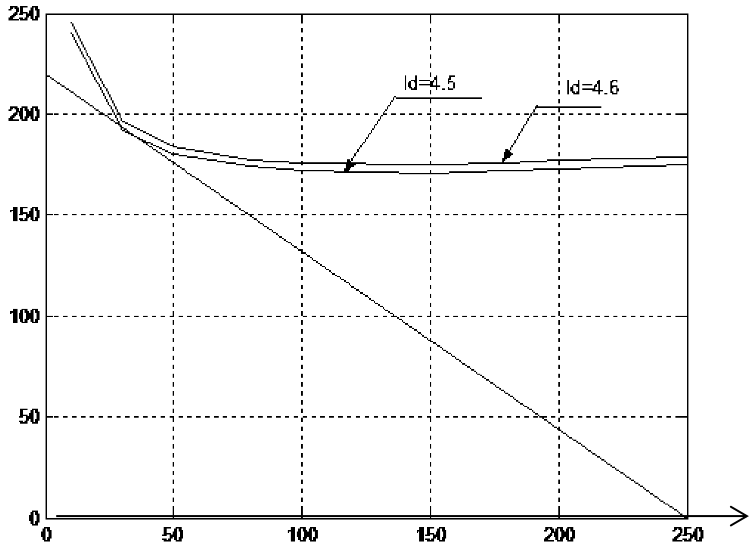

Figure 3.2 - Dependency Graph $U_a = f(I_0)$

The length of the arc will be equal to the critical length in case when we select l_a to achieve the built-in current-voltage characteristic $U_a = f(I_0)$ is located little higher than the rheostat, or touched it within one point.

It can be seen from Fig. 3.2 that the arc extinguishing conditions are satisfied when

$l_a = l_{kr} = 4{,}6$ cm.

$$t_a = \frac{\sqrt{4.6^2 - 2^2}}{3 \cdot 4637} = 2.978 \cdot 10^{-4} s$$

Arc extension, h_a:

$$h_a = V_a \cdot t_a \tag{3.7}$$

$$h_a = 4637 \cdot 2.978 \cdot 10^{-4} = 1.38 cm$$

Table 3.2 shows the results of calculations for I_{off}=2500 A

Table 3.2- Results of calculations for I_{off}=2500 A

I_a, A	10	50	100	200	500	1000	1500	2000	2500
V_a,cm/s	1466	3279	4637	6557	10370	14660	17960	20740	23180
d_a, cm	0,092	0,138	0,164	0,195	0,246	0,292	0,324	0,348	0,368
E_a, V	53,46	40	38,3	38,5	41,8	47	51	55,3	58
$U_{a\ for}$ l_a=4,6	245	184	176	177	192	216	236	254	270
$U_{д\ for}$ l_a=6	320	240	229	231	251	282	309	332	352

Figure 3.3 shows the rheostatic and volt-ampere characteristics of the arc with a breaking current of 2500 A.

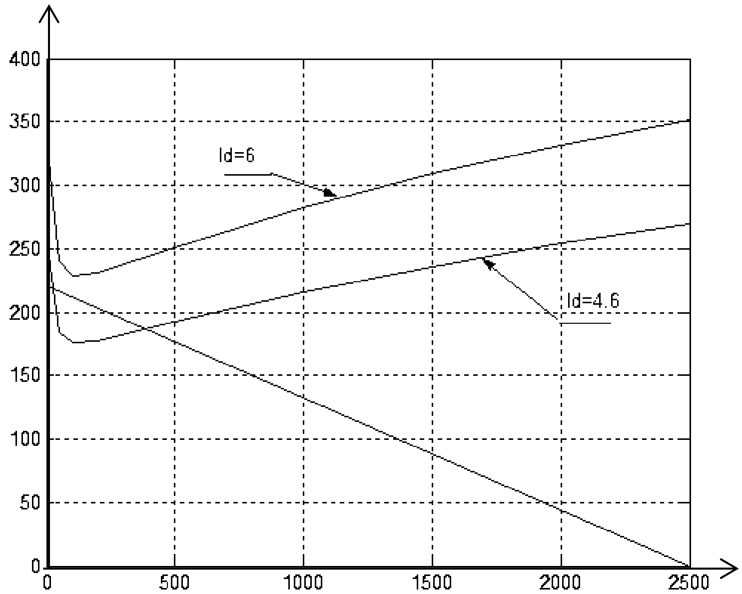

Figure 3.3 - Dependency graph $U_a = f(I_0)$

With a disconnecting current 2500 A: l_a= l_{kr} =6 cm.

$$t_a = \frac{\sqrt{6^2 - 2^2}}{3 \cdot 10370} = 1.8 \cdot 10^{-4} s$$

$$h_a = 10370 \cdot 1.8 \cdot 10^{-4} = 1.9 cm$$

At the rated and maximum disconnected current, the arc boom does not exceed the selected contact gap (β=2 cm), so the gap was selected correctly.

Figure 3.4 shows a sketch of the designed arc interrupter

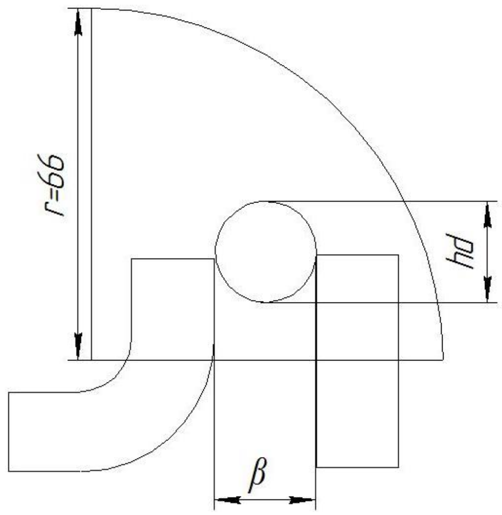

Figure 3.4 - Design of the arc interrupter

β=2 cm; h_d=1,9 cm

Cooling chamber side surface area, S_δ:

$$S_\delta = \frac{\pi \cdot d^2}{16} \tag{3.8}$$

$$S_\delta = \frac{3.14 \cdot 13.2^2}{16} = 34 cm^2$$

4 THE DESIGN OF THE APPARATUS MECHANISM

Mechanisms of contactors, usually, transmit movement within confined limits - up to the stop.

One of the main requirements for mechanism design, is that the driving forces of the mechanism must ensure the activation and deactivation of the actuating body-contacts.

Electromagnetic contactors, magnetic starters have two driving mechanisms: an electromagnetic drive – contactor switching on drive and a spring one - to disconnect the contactor. Preliminary calculation of the electromagnetic drive is possible only after calculating and plotting the characteristics of the spring drive, which is called the characteristic of opposing forces.

The main elements of the spring mechanism are contact and return springs, that create forces tearing off the armature from the core after the electromagnetic drive is disconnected.

The force of the contact pressing, brought to the axis of the contact spring, F'_k [6]:

$$F'_k = \frac{F_1 + F_2}{2} \tag{4.1}$$

where F_1 – is the initial contact pressure that is equal to 13,1 N;

F_2 – is the final click on a contact equal to 21,2 N.

$$F'_k = \frac{13.1 + 21.2}{2} = 17.2N$$

Value pre-press, F_{1v}:

$$F_{1v} = 0,3 \cdot F_2 \cdot \frac{l_1 + l_2}{l_B} k \tag{4.2}$$

where l_1 – is the distance from the axis of the contact spring to the axis of the contact assembly, equal to 50 mm;

l_2 – is the distance from the node rotation to the axis of rotation of the entire mobile system of the apparatus (up to the prism), equal to 80 mm;

l_v - distance from the spring return axis to the prism, equal to 170 mm;

k – the number of main contacts equal to 1.

$$F_{1v} = 0,3 \cdot 21.2 \cdot \frac{50 + 80}{170} \cdot 1 = 4.9N$$

Final push of return spring, F_{2v}:

$$F_{2v} = 1,3 \cdot F_{1v} \tag{4.3}$$

$$F_{2v} = 1,3 \cdot 4.9 = 6.3N$$

To construct the characteristic of opposing forces, the solution $\beta_к$, and a failure σ_n Contacts, efforts F_1 and final F_2 contact springs compression and pre-stresses F_{1v} and final F_{2v} compressed springs lead to the axis of the electromagnet coilbto its working air gap.

Let's bring the contact gap to the axis of the electromagnet, β'_k:

$$\beta'_k = \beta_к \frac{l_2}{l_1}, \tag{4.4}$$

where β_k – is the contact solution equal to 13 mm

$$\beta_k^{'} = 13\frac{80}{50} = 20.8mm$$

Let us cite the failure of the contacts to the axis of the electromagnet, $\sigma^{'}_{k}$:

$$\sigma_n^{'} = \sigma_n \frac{l_2}{l_1}, \tag{4.5}$$

where $\sigma_{п}$ – is the contact failure equal to 3 mm

$$\sigma_n^{'} = 3\frac{80}{50} = 4.8mm$$

Initial force of the contact spring, F'_1:

$$F_1^{'} = F_1 \frac{l_v}{l_2} \tag{4.6}$$

$$F_1^{'} = 13.1\frac{170}{80} = 27.8N$$

Final force of the contact spring,F'_2:

$$F_2^{'} = F_2 \frac{l_v}{l_2} \tag{4.7}$$

$$F_2^{'} = 17.2\frac{170}{80} = 23.46N$$

Initial return spring force, F'_{1v}:

$$F_{RS}^{In} = F_{1v}\frac{l_v}{l_2} \tag{4.8}$$

$$F_{RS}^{In} = 4.9\frac{170}{80} = 10.4N$$

Final spring force, F_{CS}^{Fin}:

$$F_{RS}^{Fin} = F_{RS}^{Fin}\frac{l_v}{l_2} \tag{4.9}$$

$$F_{CS}^{Fin} = 6.3\frac{170}{80} = 15N$$

The strength of an electromagnet, which it can develop with a critical gap, $F_{g.cr.}$:

$$F_{g \cdot cr} = K_g \cdot \mathrm{F}_{cr} \tag{4.10}$$

where K_g – stock factor , for contactors and magnetic starters is 1.3 - 1.7;

F_{cr} – The value of the total reactive force at the critical gap, equal to 28.7 N.

$$F_{El.m}^{\max} = 1{,}5 \cdot 42 = 60N$$

F_{Cr} – is critical value of counterforce

F_{RS}^{Cr} – is return spring force

F_1 – is initial force of the contact spring

$$F_{Cr} = 6.42 + 15.64 = 22.1$$

Figure 4.1 shows the opposing forces characteristics.

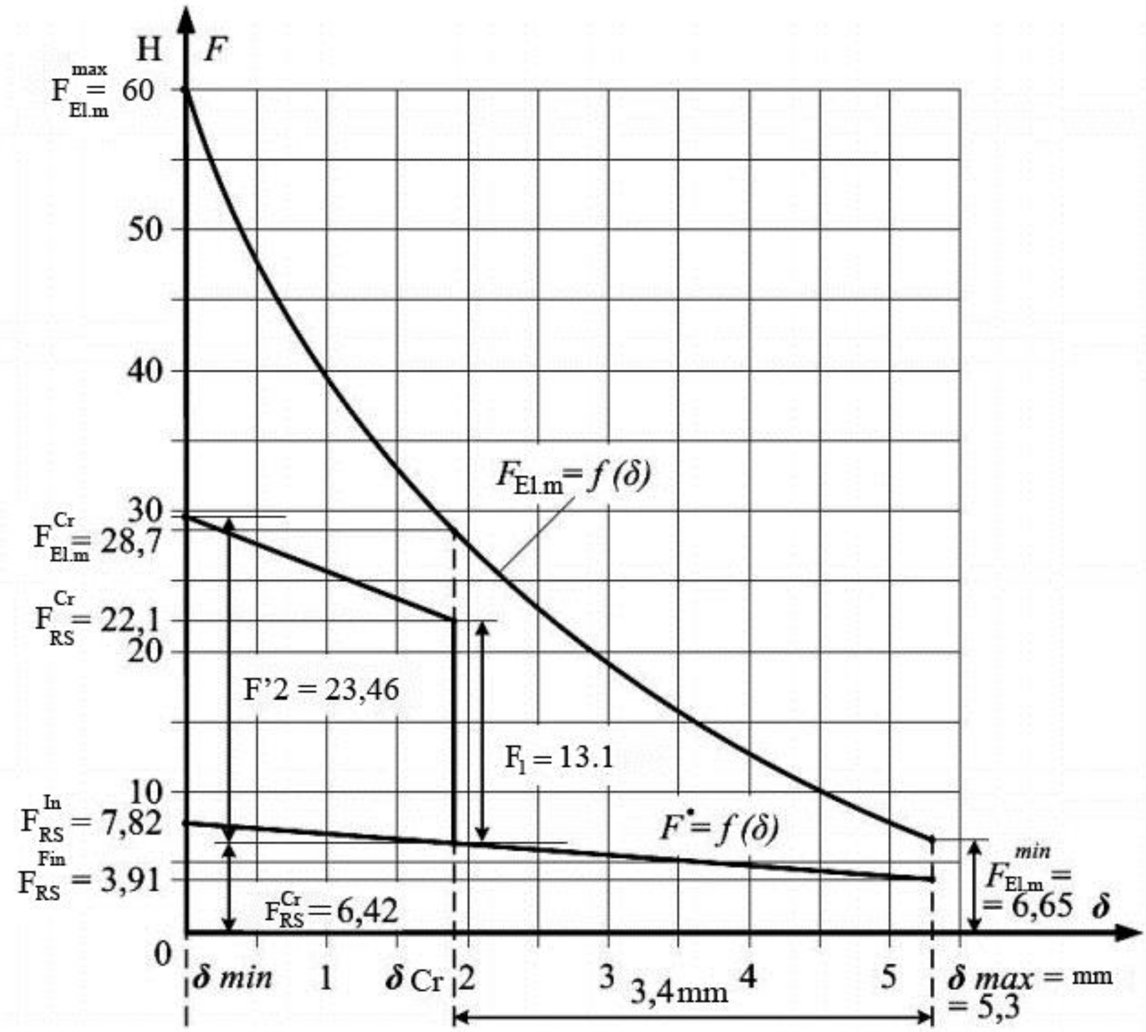

Figure 4.1 – Traction characteristic of electromagnet $F_{El.m} = f(\delta)$ and the characteristic of opposing forces $F = f(\delta)$

$$F_{El.m}^{\min} = k_{sf} \cdot F_{RS}^{In}$$

$$F_{El.m}^{\min} = 1.7 \cdot 3.91 = 6.65$$

where k_{sf} = 1.3÷1.7 – is force safety coefficient

F_{RS}^{In} = 3.91 – is the initial compression of the return spring

$F_{El.m}^{\min}$ = 6.65 – is the initial force of electromagnet (δ_{max})

5 ELECTROMAGNETIC DRIVE CALCULATION

5.1 Preliminary calculation of an electromagnet

The calculation task is the preliminary determination of the magnetic circuit dimensions, the magnetizing force of the winding, and its geometric dimensions.

For electromagnets with a pole tip, the pole piece cross-sectional area is determined by the Maxwell's formula [9]:

$$S_{p.n} = \frac{F_{g.cr} \cdot K_{zs}}{39{,}8 \cdot B_{\delta}^{2}}, \qquad (5.1)$$

wher B_{δ} – is the induction in the air gap, equal to 0.7 T;

K_{zs} – is a safety factor by force equal to 1.5

$$S_{p.n} = \frac{62 \cdot 1{,}5}{39{,}8 \cdot 0{,}7^{2}} = 12.54 cm^{2}$$

Diameter of the pole piece, d_{pn}:

$$d_{p.n} = \sqrt{\frac{4S_{p.n}}{\pi}} \qquad (5.2)$$

$$d_{p.n} = \sqrt{\frac{4 \cdot 12.54}{3{,}14}} = 4 cm$$

Core cross-section, S_c:

$$S_c = \frac{\Sigma_{vp} \cdot B_{\delta} \cdot S_{pn}}{B_{s.pr}} \qquad (5.3)$$

where Σ_{vp} – buckling coefficient equal to 1,3;

$B_{s.pr}$ – The maximum induction in the core with the armature drawn is 1.5 T.

$$S_c = \frac{1{,}3 \cdot 0{,}7 \cdot 12.54}{1{,}5} = 11.65 cm^2$$

Cross-sectional area of anchors, S_{an}:

$$S_{an} = \frac{S_c}{\Sigma_{vp}} \tag{5.4}$$

$$S_{an} = \frac{12.54}{1{,}3} = 8.96 cm^2$$

Core diameter d_c is established from the relation:

$$D_{p.n} / d_c = 1{,}2 \tag{5.5}$$

$$d_c = 3.33$$

Height of pole piece $h_{p.n}$ is determined from the relationship:

$$\frac{h_{p.n}}{d_c} = 0{,}2 \tag{5.6}$$

$$h_{p.n} = 0{,}2 \cdot 3.33 = 0.67 cm$$

Coil size, l_k:

$$l_k = \sqrt[3]{\frac{F_{kr}^2 \cdot K_{zs} \cdot t \cdot \rho}{2 f_o K_T \tau_{all} \cdot p}}, \tag{5.7}$$

where f_0– is the coefficient of winding filling equal to 0.5;

$К_т$ – is the heat transfer coefficient, is adopted for insulation class A, equal to 1,15 Wt/m^2;

P – is the power overload factor equal to 1;

F_{kr} – is the value of the magnetizing actuation force for the critical gap, N

$$F_{kr} = K_n \cdot F_\delta = \frac{B_\delta \cdot \delta \cdot K_n}{\mu_0}, \tag{5.8}$$

where $К_n$ – the coefficient that takes into account the magnetizing force drop in the non-working gaps and the steel of the magnetic circuit, equal to 1.2;

μ_0 - magnetic permeability of air equal to $4 \cdot \pi \cdot 10^{-7}$.

$$F_{kr} = \frac{0.7 \cdot 0.001 \cdot 1.2}{4 \cdot 3.14 \cdot 10^{-7}} = 517N$$

$$l_к = \sqrt[3]{\frac{517^2 \cdot 1.5 \cdot 6 \cdot 0.0175}{2 \cdot 0.5 \cdot 1.15 \cdot 105 \cdot 1}} = 7.04cm$$

The width of the anchor is equal to the yoke width:

$$b_y = b_{yw} = d_c + 2 \cdot h_k \tag{5.9}$$

where h_k – is the coil thickness, cm

$$h_k = l_k / n, \tag{5.10}$$

where n – is the coefficient for DC coils, equal to 3;

$$h_k = 7.04 / 3 = 2.35cm$$

$$b_y = b_{yw} = 2.5 + 2 \cdot 1.2 = 4.9cm$$

Thickness of yoke, a_y:

$$a_y = \frac{S_y}{b_{yw}} \tag{5.11}$$

$$a_y = \frac{8.96}{4.9} = 1.12cm$$

For design reasons, the gap between the yoke and the winding h - $h_к$, in order to reduce the scattering flux, is assumed to be 1 cm.

5.2 Coil parameters calculation

The coil is the main part of all electromagnets, providing the necessary magnetizing force (n.c.) for the operation of the electromagnet.

The calculation task is to determine the wire diameter d, the number of turns W and the winding resistance, which provide the necessary magnetizing force at acceptable heating temperatures.

Cross-sectional area of a round coil, S:

$$S = l_k \cdot h_k \tag{5.12}$$

$$S = 7.04 \cdot 2.35 = 16.51cm^2$$

The average length of the coil winding for a round coil, $l_{av:}$

$$l_{av} = \pi(d_o + h_o), \tag{5.13}$$

where d_0 – the width of the coil frame is 3.9 cm;

h_0 – the height of the coil frame is 2.35 cm.

$$l_{av} = 3{,}14(3{,}9 + 2.35) = 19.61cm$$

Diameter of round winding wire, d:

$$d=\sqrt{\frac{4\rho_o(1+\alpha\cdot T_{all})\cdot l_{cr}\cdot F_{kr}\cdot K_z}{\pi U}} \quad (5.14)$$

$$d=\sqrt{\frac{4\cdot 1{,}75\cdot 10^{-6}\cdot(1+0{,}004\cdot 105)\cdot 12{,}9\cdot 517\cdot 1{,}3}{3{,}14\cdot 220}}=0.02cm$$

From the diameter found, the wires d from the reference book, let's determine the nearest larger standard diameter of the bare wire; Diameter of insulated wire d1:

d_1=0,0225 cm.

Number of winding turns, W:

$$W=f_o\frac{4h_o l_o}{\pi d_1^2} \quad (5.15)$$

$$W=1\frac{4\cdot 2.35\cdot 6.04}{3.14\cdot 0.0255^2}=2385\ turns$$

Active winding resistance:

$$R=\frac{4\rho_o(1+\alpha\cdot T_{\partial on})\cdot l_{cp}}{\pi d^2}W \quad (5.16)$$

$$R=\frac{4\cdot 1.75\cdot 10^{-6}(1+0.004\cdot 105)\cdot 19.61}{3.14\cdot 0.02^2}9162=370.2Ohm$$

For thermal calculation it is necessary to know the maximum winding current:

$$I=\frac{1{,}05U}{R} \quad (5.17)$$

$$I = \frac{1{,}05 \cdot 220}{370.2} = 0.6A$$

Max power, P:

$$P = I^2 R \tag{5.18}$$

$$P = 0.6^2 \cdot 370.2 = 144Wt$$

Then, the value of the magnetizing force of the winding can be specified:

$$F = I \cdot W \tag{5.19}$$

$$F = 0.6 \cdot 2385 = 1488N$$

If condition F ≥ F_{av} K_z, the dimensions of the coil are suitable for the specified parameters.

$$F_{av} K_z = 517 \cdot 1{,}3 = 672{,}1 \text{ N}$$

The condition is satisfied.

To control the calculations, it is expedient to determine the current density in the winding:

$$j = \frac{I}{g} = \frac{4I}{\pi d^2} \tag{5.20}$$

$$j = \frac{4 \cdot 0.6}{3.14 \cdot 0.02^2} = 5.1A / cm^2$$

The resulting current density value is compared with the allowable value. For a short-time operation of the device, the permissible current density j_d:

J_d=5-12 A/cm^2.

The excess of the winding temperature above the ambient temperature is calculated from the Newton formula:

$$\tau_y = \frac{P}{K_T S_{col}} \tag{5.21}$$

where S_{col} – is the coil cooling surface area, cm^2;

$$S_{col} = \pi(D_o + K_B d_o) l_o, \tag{5.22}$$

where K_b – is the coefficient, that characterizes the ratio of heat transfer of the inner and outer surfaces of the coil, equal to 0.2.

$$S_{col} = 3.14 \cdot (9.02 + 0.2 \cdot 3.9)7 = 82 cm^2 \tau_y \le \tau_{all}$$

The criterion for accessing correctness of the winding calculation is the fulfillment of the condition:

$$\tau_y = \frac{144.2}{1.15 \cdot 0.82} = 55^o C$$

where τ_{all} - permissible excess of the winding temperature above the ambient temperature, determined by the class of heat resistance of the wire insulation.

Condition performed.

For the most frequently used winding wire with enamel insulation of PEL grade, the permissible temperature τ_{all} = 85 °C.

6 DESIGN DEVELOPMENT

The contactor design is the monoblock. All structural elements are assembled on the main Z-shaped bracket.

The magnetic system of the apparatus is made of a continuous strip and a round core.

The contactor electromagnet includes a coil with a magnetizing coil located on it, a fixed part of a magnetic circuit made of a ferromagnetic material (yoke and core) and a movable part of a magnetic circuit (armature).

The electromagnet anchor is made of sheet steel with a thickness of 25 mm. To eliminate sticking anchors use non-magnetic gaskets.

The coil frame is a molded carbolite case.

The coil of the electromagnet is wound with a copper enameled wire with insulation based on oil varnishes (PEL) 0.02 cm in diameter, 2385 windings are wound.

A L-shaped armature is inserted into the slot of the main bracket of the magnetic core, on which a bracket-bracket is attached, which carries a movable contact with the contact spring.

The bracket is made of strip steel and is attached to the insulating panel. Workpiece length 360 mm.

The main material of contacts is cadmium copper. It has a lower specific resistance and greater mechanical strength, compared with other alloys. Cadmium coating is used to protect against corrosion.

For continuous operation of the contactor without reducing the rated current, the contacts are made with silver solder.

The contactor is installed only on the insulating panel, since the housing is under voltage.

The contactor has a magnetic damping of the arc in a chamber with a wide slit.

The arc chute can be easily removed without unscrewing any parts.

Most of the contactor chambers are made of asbestos cement material - a solid material of cold compacting of a purely inorganic composition, in which the filler is asbestos, and the binder is cement. In the manufacture of asbestos cement, the fluffed asbestos fiber is mixed with cement and water and pressed, the cement hardens under the action of water and firmly bonds the asbestos fibers.

Asbestos cement has high electrical insulating properties, but it has considerable hygroscopicity and high toxicity in its production and operation, therefore the camera of the designed contactor is made of a material based on glass fibers with an unsaturated polyester compound. This material has a high arc resistance, as well as it does not contain halogens. This material also has a high resistance to leakage currents under severe operating conditions.

7 ECONOMIC SECTION

The idea is to produce 110 V, 110 A direct current conductors. This electrical apparatus is used in general industrial stationary plants control circuits.

Table 1 shows the preliminary characteristic of the potential market:

Table 1 – Potential market preliminary characteristic

№	Market indicators (Names)	Characteristic
1	Main competitors	KPV Contactors
		KPD Contactors
		SIEMENS Contactors
2	Market dynamics (qualitative evaluation)	Growing
3	Market entry restrictions	advertising, customer loyalty, network effect, partner arrangement

Table 2 shows the preliminary characteristic of potential clients.

Table 2 – Potential clients preliminary characteristic

№ п/п	The need, that forms the market	Target audience (target market segments)	Consumer demands (users)
1	The need to switch direct current circuits	Industrial enterprises “Zaporizhstal” “Motor-Sich”	Reliability an maintainability, competitive price
2	The need to switch industrial plant control circuits	Workshops, equipped with general industrial stationary plants	Long lifetime and relative simplicity of the design

SWOT- analysis is shown as the table 3.

Table 3 - SWOT- analysis

Strengths:	Weaknesses:
- high quality, reliability and maintainability. - competitive price	- weak reputation on the market; - the absence of extensive client base
Opportunities:	Risks:
- new contract signing; - global market entering. - the production increase	- highly competitive market; -relatively small target audience.

SWOT-analysis showed, that the idea has some strengths and opportunities, but there are also some weaknesses and risks.

The number of hours in the effective working time fund is determined by the formula:

$$К_{р.г.рік} = К_{.г} \cdot К_{р.дн}, \tag{7.1}$$

where

$К_{р.г}$ — working hours number per day, if the working week is 40 hours;

$К_{р.дн}$ —the official enterprice working days number in 2021;

$$К_{р.дн} = Д_{ка} – Д_{св} – Д_{вих} – Д_{нр} \tag{7.2}$$

where $Д_{ка}$ – calendar days number

$Д_{св}$ – the number of holydays

$Д_{вих}$ – the number of weekends

$Д_{нр}$ – the day-off number

$$К_{р.дн} = 356 – 52 – 52 – 10 – 4 = 247$$

$$К_{р.г.рік} = 8 \cdot 247 = 1976\ hrs.$$

Tariff rate was determined by the formula:

$$Т = ЗП \div (РГ \div 12), \tag{7.4}$$

where ЗП — the average salary ex officio;

РГ — the number of working hours in 2021;

12 — the number of months in one year.

$$Т1 = 13000 \div (1976 \div 12) = 78.95\ UAH/hour$$

$$Т2 = 10000 \div (1976 \div 12) = 60.72\ UAH/hour$$

$$Т3 = 7500 \div (1976 \div 12) = 45.55\ UAH/hour$$

The tariff income per year is determined by the formula:

$$Тз = Т \cdot РГ; \quad (7.5)$$

$$Тз1 = Т1 \cdot РГ = 78.95 \cdot 1976 = 156000\ UAH;$$

$$Тз2 = Т2 \cdot РГ = 60.72 \cdot 1976 = 120000\ UAH;$$

$$Тз3 = Т3 \cdot РГ = 45.55 \cdot 1976 = 90010\ UAH;$$

The bonus level per year is determined by the formula:

$$П = Тз \cdot Пв, \quad (7.6)$$

where Пв — bonus percentage;

Тз — tariff income per year.

$$П1 = Тз1 \cdot Пв1 = 156000 \cdot 0.15 = 23400\ UAH;$$

$$П2 = Тз2 \cdot Пв2 = 120000 \cdot 0.1 = 12000\ UAH;$$

$$П3 = Тз3 \cdot Пв3 = 90010 \cdot 0.1 = 9001\ UAH.$$

Total annual wages for each particular personnel class is determined by the formula:

$$Фзп = (Тз + П) \cdot к, \quad (7.7)$$

where к — is the number of personnel of a particular class.

$$Фзп1 = (Тз1 + П1) \cdot к1 = (156000 + 23400) \cdot 15 = 2691000\ UAH;$$

$$Фзп2 = (Тз2 + П2) \cdot к2 = (120000 + 12000) \cdot 7 = 924000\ UAH;$$

$$Фзп3 = (Тз3 + П3) \cdot к3 = (90010 + 9001) \cdot 10 = 990100\ UAH.$$

Overall wage bill is determined by the next formula:

$$Фзп.з = Фзп1 + Фзп2 + Фзп3 = 2691000 + 924000 + 990100 = $$
$$= 4605100\ UAH.$$

The ESV rate is equal to 22%, then the calculation is carried out according to the next formula:

$$ЄСВ1 = Фзп1 \cdot 22\% = 2691000 \cdot 0.22 = 592020\ UAH;$$
$$ЄСВ2 = Фзп2 \cdot 22\% = 924000 \cdot 0.22 = 203280\ UAH;$$
$$ЄСВ3 = Фзп3 \cdot 22\% = 990100 \cdot 0.22 = 217822\ UAH.$$
$$ЄСВзаг = ЄСВ1 + ЄСВ2 + ЄСВ3 = 592020 + 203280 + 217822 = $$
$$1013120\ UAH.$$

The award is determined by the formula:

$$П = ПО \cdot П\%, \quad (7.8)$$

where ПО — official salary;

П% — official salary bonus.

$$П1 = 25000 \cdot 0.15 = 3750\ UAH;$$
$$П2 = 15000 \cdot 0.1 = 1500\ UAH.$$

Monthly salary is determined by the formula:

$$ЗПм = ПО + П, \quad (7.9)$$
$$ЗПм1 = ПО1 + П1 = 25000 + 3750 = 34500\ грн;$$
$$ЗПм2 = ПО2 + П2 = 15000 + 1500 = 16500\ грн.$$

Table 4 shows the calculation of the production staff salary expanses.

Table 4 – Composition, size and wage bill for the production staff

Staff classes	Staff number, people		Tariff rate, UAH / hour	Effective working time fund, hours	Tariff income, UAH.	award percentage to the tariff income	The award, UAH.	Total annual wages, UAH.	ESV, UAH.
	per duty	per day							
1	2	3	4	5	6	7	8	9	1
Production staff: 1.Main staff	15	15	78.95	1976	156000	15	23400	2691000	592020
2. Secondary staff	7	7	60.72	1976	120000	10	12000	924000	203280
3.Maintenance force and the duty staff	10	10	45.55	1976	90010	10	9001	990100	217822
Total number of production staff	32	32	X	X	X	X	44401	4605100	1013122
Total									3071850

Raw material costs are calculated according to the formula:

$$МВ = ОС \cdot Ц, \tag{7.10}$$

where ОС — the amount of raw material, kg;

Ц — raw material price, UAH /kg.

$$ОС = Н \cdot ВП, \qquad (7.11)$$

where Н — calculation nor per one product unit, kg;

ВП — production program, pc.

$$ОС1 = 0.02 \cdot 6500 = 130\ kg;$$

$$ОС2 = 0.5 \cdot 6500 = 3250\ kg;$$

$$ОС3 = 0.7 \cdot 6500 = 4550\ kg;$$

$$МВ1 = 130 \cdot 15000 = 1950000\ UAH;$$

$$МВ2 = 3250 \cdot 120 = 390000\ UAH;$$

$$МВ3 = 4550 \cdot 7 = 31850\ UAH.$$

$$МВзаг = МВ1 + МВ2 + МВ3 + МВ4 =$$

$$= 1950000 + 390000 + 318500 + 700000 = 3071850\ UAH.$$

Table 5 shows the calculation of raw material expanses and materials for contactor producing.

Table 5 –Material expenses calculation

Material expenses	Standard per unit of product, kg	Production program, pcs	Raw material amount, kg	Price per 1 kg	Sum, UAH
1	2	3	4	5	6
Technical silver	0.02	6500	130	15000	1950000
Copper	0.50	6500	3250	120	390000
Steel	0.70	6500	4550	7	31850
Other materials	-	6500	-	-	700000

Consumed service price is calculated by the next formula:

$$ВСП = ОП \cdot Т, \tag{7.12}$$

where ОП — service amount;

Т — single service tariff.

$$ОП = Н \cdot ВП, \tag{7.13}$$

where Н — a standard per single product;

ВП — production program, pcs.

$$ОП1 = Н1 \cdot ВП = 1.5 \cdot 6500 = 9750\ UAH;$$
$$ОП2 = Н2 \cdot ВП = 0.7 \cdot 6500 = 4550\ UAH;$$

$$ВСП1 = ОП1 \cdot Т1 = 9750 \cdot 1.01 = 9848\ UAH;$$
$$ВСП2 = ОП2 \cdot Т2 = 4550 \cdot 16 = 72800\ UAH;$$

Table 6 shows the calculation of consumed service for contactor production.

Table 6 – Consumed service price calculation

Type of the service	The standard per single product. (service)	Production program	Service amount	Tariffs	Sum, UAH
1	2	3	4	5	6
Power supply	1.5	6500	9750	1.01	9848
Water supply	0.7	6500	4550	16	72800
Total					82648

Amortization norm is calculated by the formula:

$$НА = Пвapт\backslash ТКВ, \quad (7.14)$$

where Пварт — primary cost, UAH;

ТКВ — the main exploitation term, years.

$$НА1 = Пварт1\backslash ТКВ1 = 2000000\backslash 15 = 133333\ UAH;$$
$$НА2 = Пварт2\backslash ТКВ2 = 1200000\backslash 10 = 120000\ UAH;$$
$$НА3 = Пварт3\backslash ТКВ3 = 1000000\backslash 5 = 200000\ UAH.$$

The annual amortization royalties percentage for single object type has been provided by the accounting department. It is calculated by the straight method that means the deviation of amortization price by the number of years during which the object is used.

Table 7 shows the calculation of main means amortization, taking into account their initial price.

Table 7 – Amortization calculation

Main means group	Amortization norm	OZ initial value by 01.01	Received OZ		Sum UAH
			Date	in. price.	
1	2	3	4	5	6
Machinery and equipment	6.666%	2000000	01.01	2000000	133333
Vehicles	10%	1200000	01.01	1200000	120000
Production and household	20%	1000000	01.01	1000000	200000

equipment					
Total		4200000		4200000	453300

The table above shows calculated expenses for all production volume.

Calculated expenses per product unit are calculated by the formula:

$$\text{Витр.}1 = \text{Витр.в.обсяг}/\text{обсяг.прод};$$

Running repair expenses were taken as 2% from main means balance cost.

Table 8 shows the cost estimate calculated per single product unit and for all production volume.

Table 8 – Cost estimate

Costing items	Expenses	
	Calculated per unit of product, UAH.	Calculated for all production volume, UAH.
Raw materials	472.592	3071850
Power supply	1.515	9848
Water supply	11.2	72800
Total	485.307	3154498
Production staff salary	708,48	4605100
ESV	155.9	1013120
Amortization	69.75	453300
Maintenance, main means operation costs	12.923	84000
Common production expenses	947	6155522
Production cost	1432,307	9310000
Administrative expenses	101.91	662460

Full cost	1534.154	9972000

The income is calculated by the formula:

$$Д = ОР \cdot Ц, \qquad (7.15)$$

where ОР — sales volume, pcs;

Ц — price, UAH.

$$Д1 = ОР1 \cdot Ц1 = 800 \cdot 2500 = 1960000\, UAH;$$
$$Д2 = ОР2 \cdot Ц2 = 1200 \cdot 2500 = 2800000\, UAH;$$
$$Д3 = ОР3 \cdot Ц3 = 1500 \cdot 2500 = 3360000\, UAH;$$
$$Д4 = ОР4 \cdot Ц4 = 1800 \cdot 2500 = 4200000\, UAH.$$

Expenses are calculated by the next formula:

$$В = ОВ \cdot СБ, \qquad (7.16)$$

where ОВ — production volume, pcs;

СБ — single product cost, UAH.

$$В1 = ОВ1 \cdot СБ = 1200 \cdot 1534 = 1840800\, UAH;$$
$$В2 = ОВ2 \cdot СБ = 1500 \cdot 1534 = 2301000\, UAH;$$
$$В3 = ОВ3 \cdot СБ = 1800 \cdot 1534 = 2761200\, UAH;$$
$$В4 = ОВ4 \cdot СБ = 2000 \cdot 1534 = 3068000\, UAH.$$

Financial result is calculated by the next formula:

$$ФР = Д - В. \qquad (7.14)$$

$$ФР1 = Д1 - В1 = 1960000 - 1840800 = 119200\ UAH;$$
$$ФР2 = Д2 - В2 = 2800000 - 2301000 = 499000\ UAH;$$
$$ФР3 = Д3 - В3 = 3360000 - 2761200 = 598800\ UAH;$$
$$ФР4 = Д4 - В4 = 4200000 - 3068000 = 1132000\ UAH;$$

Table 9 shows the innovative project financial result and estimated income calculation.

Table 7.9 – Financial results calculation

№ of period	Producti volume	Price	Income	Expense s	Financial result
1	1200	2800	1960000	1840800	119200
2	1500	2800	2800000	2301000	499000
3	1800	2800	3360000	2761200	598800
4	2000	2800	4200000	3068000	1132000
Total	6500	X	12320000	9971000	2349000

After the financial result calculation it's possible to calculate the payback period:

$$ТО = СВ/Д, \tag{7.17}$$

where СВ — investments amount, UAH;

$Д_р$ — annual income, UAH.

$$ТО = 9971000/12320000 = 0{,}809 \text{ years.}$$
$$ТО = 0{,}809 \cdot 12 = 9.7 \approx 10 \text{ months.}$$

Conclusion:

During diploma project economic section calculation, a complex economic calculation for 110V 110A DC contactor production. During this calculation, the preliminary market and customer characteristics were given. Production cost estimate was calculated and the SWOT-analysis was carried out. The results of economic calculation showed that, the innovative project financial results brought the pure income of 2349000 UAH. The Payback period is 10 months.

8 OCCUPATIONAL SAFETY

The purpose of labor protection at the enterprise is to provide specialists with such a body of knowledge and skills that in the conditions of production they can make adequate decisions by means of which the organization of labor, technological equipment and machines that are operated or will be put into operation could not be the source of extraordinary events, accidents with negative traumatic consequences.

According to the subject of the diploma project "A switching device for general industrial stationary plants" – it is planned to perform calculations in workplaces equipped with personal computers. Therefore, further consider the working conditions of the engineer when performing work on computer equipment.

The workstation includes the computer, the monitor, the keyboard, the input device, the software, the desk / work surface, the chair as well as the space for performing work (work environment). The workstation means an assembly comprising display screen equipment – computer screens and microfiche readers and applies to conventional cathode ray tube display screens liquid crystal displays (alphanumeric and graphic display screen).

When providing work at the laboratory with PC (VDU) the general use of the equipment and appropriate premise should not be a source of risk for PC operators. The analysis of harmful and danger occupational effects in order to evaluate the safety and health conditions will be considered below and on the basis of the evaluation adequate measures to remedy risks found are taken.

In a workplace equipped with computer equipment (visual display units VDU), the operator is exposed to hazardous factors (GOST 12.0.003-74 “Occupational safety standards system. Dangerous and harmful production effects. Classification”), such as:

- possibility of electric shock;
- increased level of electrostatic field;

- fire danger;
- increased noise and vibration level;
- unsatisfactory illumination level;
- unsatisfactory sanitary conditions;
- non-compliance with ergonomic requirements of monitor characteristics and workplace equipment;
- an increased level of psycho-physiological stress of the nervous system, mental strain, work monotony, emotional overload.

All these factors can adversely affect the health of the operator. Unsatisfactory work conditions lead to deterioration of the person's well-being, a decrease in labor productivity and an increase in susceptibility to the disease. Violation of occupational safety requirements can lead to accidents, injuries, traumas and occupational diseases.

Non-compliance with ergonomic requirements, monitor characteristics and workplace equipment lead to a number of diseases and ailments, such as: eye diseases and visual impairments, due to a constant tense look at the monitor screen, and as a result - blindness, headache, fatigue and dizziness drowsiness in the course of the day musculoskeletal system, skin disease, impaired reproductive function, on the severity of the skin of the forehead and head; loss of hair. All these diseases are caused by the danger of using information equipment, imperfect organization of work of users of computer equipment.

Long-term work at the computer leads to negative consequences on the eyes and eyesight. Display of illness is characterized by impaired eye accommodation due to prolonged overstrain of the ciliary body. Dry eye syndrome is a collective name for a disease caused by a dull fluid in the anterior surface of the eye (cornea). Normally, a person carries out more than 20 blinking movements per minute. While working at the computer, the blink frequency decreases at least three times. In this case, the surface of the cornea "dries up." Dry eye syndrome develops after a while working at the computer and is manifested by burning in the eyes, reddening of the conjunctiva, the appearance of a vascular network on the lateral surfaces of the eyes.

In tandem with the long work with the use of computer technology, a person is at an increased level of psychological stress of the nervous system, which leads to: fatigue, decreased ability to concentrate attention, perceive information, reduce the ability to remember and mention, changes in emotional state (depression, irritation, emotional balance lose). Through this condition, there are psychological disorders, impaired functions of the gastrointestinal tract, sleep, changes in heart rate, etc.

Computer users who do not receive adequate training on occupational safety, including how recognize hazards and reduce / eliminate them are of great risk of harm. In accordance with the requirements of NPAOP 0.00-4.12-05 “Typical regulation of arrangement about training and occupational safety knowledge test”, the relevant regulations of enterprises on training on labor protection are developed and approved. In order to prevent undesired possible injuries, all employees and students during their work practice are to pass the instructions on occupational safety. Besides the issues of the use and maintenance of computer equipment to accommodate individual characteristics, ergonomics, favorable working postures, recognition of symptoms of computer-related diseases are of great importance.

Possible causes of electric shock:

- damage to the insulation (factory waste, aging, pollution, mechanical damage, mechanical wear, deliberate damage to equipment);
- accidental contact with current-carrying parts;
- absence of earthing;
- closure in the result of an accident.

The project provides for measures to protect the user of computer equipment from exposure to harmful and dangerous factors.

Methods of protection from electric shock:

- protection against accidental contact with live parts;
-protective grounding, zeroing, equalization of electrical potentials;

-protective switch-off;

-the application of a safe voltage;

-control and prevention of insulation damage;

-respective qualification and experience of a person.

The main ergonomic recommendations for electrical safety are to reroute, secure and cover stray leads, replace frayed leads and damage plugs, avoid overloading extension leads and coiled cables overheating and so on.

The PC laboratory electric equipment is supplied from 220 VAC network and with 50 Hz frequency. According to the requirements of «PUE», the electric equipment in PC laboratory are characterized as electric equipment of 1000 V, then according to the requirements of «PUE» and GOST 12.1.030-81 (2001) «SSBT. Electric safety. Protective grounding, nulling», the value of protective grounding circuit electric equipment resistance of laboratory with PC (VDU) does not exceed 4 Ohm.

While the computer is running, it is forbidden:

- to leave the computer unattended;

-to carry out any repairs;

-to remove the case from the computer.

According to ISO 9241-6:1999 “Ergonomic requirements for office work with visual display terminals (VDTs)” the design and arrangement of the work environment are governed by work organization factors, individual’s personal environment and other occupational effects.

In accordance with DSANPIN 3.3.2.007-98 “State sanitary rules and regulations for working with visual display terminals of electronic computers”, the personal computer operator workplace is provided.

The area of 6 m^2 of space for one PC operator in the laboratory is provided. PC workstations are located relative to the windows so that natural light falls from the side, mainly on the left. The distance between desktops with video monitors is 2.2 m, and the distance between the side surfaces of video monitors - not less than

1.5 m, which meets the established standards. Optimal working posture is provided by the design of operator's workplace.

The monitor is at a distance of 650 mm from the user's eyes. The top of the screen is at / below the eye level. The viewing angle of the screen is 30º below the horizontal eye level that meets the requirements. The characters on the screen are well defined and clearly formed; a minimum character height of between 3.l mm to 4.2 mm is recommended. The image on the screen is stable, with no flickering and instability, the signal is continuously refreshed (50 hertz refresh rate). At the same time, the reflection coefficient of the workplace is 0.6.

The desktop design provides optimal placement of the equipment used on the work surface. The rational working posture is provided by the design of the work chair that allows to change the working posture and reduce the tension of neck and back muscles. The keyboard is located on the table at a distance of 150 mm from the edge facing the operator, or on a special, height-adjustable work surface that is separated from the main desktop.

Lighting has a direct impact on safety and productivity. Insufficient or excessive, uneven illumination in the field of vision wears the eyes, leads to a decrease in labor productivity, while the potential danger of mistakes and accidents increases, and can lead to diseases: dry eyes, myopia, glaucoma, destruction of the eyeball, etc. Excessive brightness of light sources can cause headache, pain in the eyes, visual acuity, light glare to temporary blindness. For the most computer tasks, including the average illuminance level is nearly 350 lux (the recommended illumination for working with the display screen is 300 lux; when working with the screen in conjunction with work on documents 400 lux is recommended), that meets the requirements of DBN V.2.5-28:2018 "Engineering equipment of buildings and constructions. Natural and artificial lighting"**.** The system of general uniform lighting in the laboratory with PC is installed.

VDU equipment emit a certain amount of heat. Too high air temperatures can lead to a heat stroke, which is accompanied by loss of consciousness, vomiting, convulsions. For safe and comfort work, the following parameters are ensured: at 18 to 24 ºC the relative humidity can fluctuate between 30% and 70%. During summer the air temperature in the laboratory is between 23ºC and 26ºC; the air velocity is at the level of 0.1-0.25 m/s. During winter the air temperature in the laboratory is between 20ºC and 24ºC; the air velocity is at the level of 0.1-0.15 m/s. Microclimate parameters are ensured according to GOST 12.1.005-88 "Occupational safety standards system. General sanitary requirements for working zone air".

The workplace is well ventilated. On the one hand, this is important for cooling different parts of the computer, which generates heat during operation (system unit, monitor, printer, etc.), and on the other hand, the supply of fresh air provides sufficient oxygen for the body. Ventilation, heating and air conditioning is performed according to DSN 3.3.6.042-99 "Sanitary norms of microclimate of industrial premises".

At workplaces with computer equipment, the main sources of noise are the fans of the system unit, the drive, impact printers. Acoustic noise and other peripheral devices can become a source of stress and discomfort for the user, reduce mental performance, increase fatigue, reduce attention, contribute to the emergence of headaches, etc. Depending on the level and nature of the noise, its duration, and also on the individual characteristics of a person, even a small noise (50-60 dB) creates a significant load on the nervous system of a person and has a psychological effect on it. Sound levels of operator’s PC and general sound pressure levels meet the requirements of DSANPIN 3.3.2.007-98 "State sanitary rules and regulations for work with visual display terminals of electronic computers" and DSN 3.3.6.037-99 “Sanitary standards of production noise, ultrasound and infrasound” and do not exceed 50 dBA.

There’re several means that allow to reduce the noise level:

- using PC’s with power supplies that have fans on rubber suspension;
- using PC’s with so-called VOC-processors, that have a fan installed onto it;
- using ATX motherboards that allow to adjust the a autonomic fan speed;
- using printers that are located relatively far from workplaces;

- using sound isolation on walls of cabins and rooms.

The rational mode of work and rest promotes reduction of fatigue, maintenance of high operability of the operator of computer equipment, increase of productivity of its work and health preservation. When determining the number of rest breaks, determining their duration and distributing them during the working shift, it is necessary to take into account the specifics of production, the intensity of work, the change in the working capacity of a person in the course of work, and preferably for each of the breaks to ventilate the workroom.

According to the DSTU EN V.1.1-36:2016 “Determination of premises, houses and external installations classes according to blast-fire and fire safety”, the premises with the personal computers belong to productions of a category "D" on fire danger. Since the fire danger category is "D, then according to requirements DBN.1.1-7:2016 “Construction sites fire safety. General requirements.” it has the II degree of fire resistance.

In accordance with the requirements NAPB B.06.004-97 "The list of one-type intension objects, that must be equipped with automatic fire alarm and fire extinguishing systems", and DBN V.2.5-13-98 "Engineering equipment of houses and buildings. Automatic fire alarm system for houses and buildings" all the premises with computers are equipped with automatic fire alarm system.

Portable carbon dioxide fire extinguishers and smoke detectors are provided. They were calculated according to NAPB B.03.001-2004 "Typical norms for fire extinguishers". The Maximum permissible concentration of fire extinguishing liquid was taken into account in accordance with the requirements of «Fire safety regulations in Ukraine». The approaches to places where all of the fire extinguishers are located are free.

In accordance with the requirements "Typical norms for fire extinguishers", DSTU EN 4297:2004 «Fire engines. Fire extinguishers technical maintenance. General technical regulations», carbon dioxide fire extinguishers of the BBK-2 type are provided in amount of at least 1 fire extinguisher for every 20 m^2 of the room area.

CONCLUSIONS

The following was determined during 110 V, 110 A DC Contactor design:

- Current-carrying circuit bus bar cross-section;

- the number of bolts in the contact connection;

- mobile system of machinery mechanism and parts of the drive mechanism;

- magnetic circuit parameters;

- Coil - frame, the location of the winding, pins, internal and external insulation, as well as fixing the coil to the magnetic circuit;

Arc interrupter;

- current-carrying parts of the apparatus, terminal clamps and their mounting to other parts of the apparatus;

In accordance with the class of heat resistance A, for the coil of the electromagnet of the contactor the enameled winding wire of the PEL brand is used.

The cost and price of the designed product were calculated. During the calculation, the cost of raw materials and basic materials was determined. Copper, aluminum, steel, asbestos cement are among them.

The purchase price of components is determined. The component products include the components of the designed contactor.

The calculated salary per unit of output corresponds to the category of work performed for certain operations.

In the work there are requirements for labor protection when working with computer equipment because according to the subject of the course project "A switching device for general industrial stationary plants", it’s envisaged to perform calculations in workplaces equipped with personal computers

REFERENCES

1. Александров, Г. Н. Проэктирование электрических аппаратов: учебник для вузов [Текст] / Г.Н. Александров,В. В. Борисов, Г.С. Каплан и др.; под ред. Г. Н. Александрова. – Л.: Энергоатомиздат, Ленингр. отд-ние, 1985. – 448 с.

2. Александров, Г. Н. Теория электрических аппаратов: учебник для вузов [Текст] / Г. Н. Александров. – М.: Высшая школа, 1985. – 312 с.

3. Близняков, О. В. Дослідження та випробування електричних апаратів: Навчальний посібник [Текст] / О. В. Близняков.
– Запоріжжя: ЗНТУ, 2005. – 94 с.

4. Дмитриевский, В. С. Расчет и конструирование электрической изоляции [Текст] / В. С. Дмитриевский. – М. Энергоатомиздат, 1981. – 392с.

5. Клименко, Б. В. Електричні апарати. Електромеханічна апаратура комутації, керування та захисту. Загальний курс: навчальний посібник [Текст] / Б. В. Клименко. – Харків: Точка, 2012. –340 с.

6. Клименко, Б. В. Електричні та магнітні пристрої, електричні аксесуари, електричні установки. Терміни, тлумачення, коментарі: навчальний посібник [Текст] / Б. В. Клименко. – Харків: Точка, 2009. – 272 с.

7. Клименко, Б. В. Комутаційна апаратура, аппаратура керування, запобіжники. Терміни, тлумачення, коментарі: навчальний посібник [Текст] / Б. В. Клименко. – Харків: Талант, 2008. – 208 с.

8. Романычева, Э.Т. Разработка и оформление конструкторской документации РЭА: Справочное пособие. [Текст] /Э. Т. Романычева и др. – М.: Радио и связь, 1983. – 256 с.

9. Сахаров, П.В. Проєктирование электрических аппаратов [Текст]/ П. В. Сахаров. – М.: Энергия,1977. 560 с.

10. Снігірьов, В.М. Електромеханічні апарати автоматики [Текст]/

В.М.Снігірьов, Л.Б. Жорняк. – Запоріжжя: ЗНТУ, 2016 – 120 с. Електронний рерурс: http://eir.zntu.edu.ua/handle/123456789/3991

11. Справочник конструктора РЭА [Текст] / Под ред. Р. Г. Варламова. – М.: Радио и связь, 1985. – 354 с.

12. Таев, И. С. Электрические аппараты управления [Текст] / И.С. Таев. – М.: Высшая школа,1984. – 247 с.

13. Чунихин, А.А. Электрические аппараты [Текст]/ А.А.Чунихин. – М.; Энергоатомиздат, 1988. – 720 с.

14. ДСТУ ГОСТ 2.307:2013 Единая система конструкторской документации. Нанесение размеров и предельных отклонений (ГОСТ 2.307-2011.IDT).

15. Снігірьов В. М. Електромеханічні апарати автоматики / В. М. Снігірьов, Л. Б. Жорняк. – Запоріжжя : ЗНТУ, 2016 –120 с.

16. Методичні вказівки до виконання дипломного проєкту бакалавра студентами спеціальності 141 «Електроенергетика, електротехніка та електромеханіка» (освітні програми «Електричні та електронні апарати» та «Електромеханічне обладнання енергоємних виробництв») всіх форм навчання / уклад.: П. Д. Андрієнко, Л. Б. Жорняк, В. В. Василевський. – Запоріжжя: НУ «Запорізька політехніка», 2020. – 66 с.

17. Методичні вказівки до виконання курсового проєкту з дисципліни «Основи проєктування електромеханічних пристроїв та систем» студентами спеціальності 141 «Електроенергетика, електротехніка та електромеханіка» (освітні програми «Електричні та електронні апарати» та «Електромеханічне обладнання енергоємних виробництв») всіх форм навчання/ уклад.: Л. Б. Жорняк, О. О. Каплієнко, І.С. Шило. – Запоріжжя: НУ «Запорізька політехніка», 2020. – 40 с.

18. Методичні вказівки до виконання курсового проєкту за фахом студентами спеціальності 141 «Електроенергетика, електротехніка та електромеханіка» (освітні програми «Електричні та електронні апарати» та

«Електромеханічне обладнання енергоємних виробництв») всіх форм навчання / уклад.: П. Д. Андрієнко, Л. Б. Жорняк, В. В. Василевський. – Запоріжжя: НУ «Запорізька політехніка», 2020. – 43 с.

19. Методичні вказівки до виконання лабораторних та контрольних робіт з дисципліни «Електричні апарати керування» студентами, що навчаються англійською мовою, на денній формі навчання для підготовки бакалаврів за спеціальністю 141 «Електроенергетика, електротехніка та електромеханіка» за освітньою програмою «Електричні та електронні апарати» / уклад.: Л. Б. Жорняк, С. В. Войтенко – Запоріжжя : ЗНТУ, 2018. – 82 с.

20. Методичні вказівки до виконання лабораторних та контрольних робіт студентами всіх форм навчання при вивченні дисципліни «Електричні апарати керування» для підготовки бакалаврів за спеціальністю 141 «Електроенергетика, електротехніка та електромеханіка» з подальшим навчанням за освітньою програмою «Електричні та електронні апарати» / уклад.: Л. Б. Жорняк, В. В. Василевський – Запоріжжя : ЗНТУ, 2019. – 86 с.

21. Методичні вказівки до виконання розділу «Охорона праці» в дипломних проектах (роботах) студентів - бакалаврів усіх спеціальностей, денної та заочної форм навчання / Укл.: М. О. Журавель, С. М. Журавель – Запоріжжя: ЗНТУ, 2018 – 24 с.

22. ДСТУ ГОСТ 12.0.003-2015 «Система стандартов безопасности труда. Опасные и вредные производственные факторы» (12.0.003-2015.IDT).

23. Контактор КПД-114. веб-сайт. URL: http://www.energotk.ru/.

24. Контакторы КПВВ и КТПВ веб-сайт. URL: http://www.avtomats.com.ua/.

25. Электромагнитные контакторы веб сайт URL: www.electricalschool.info/spravochnik/apparaty/jelectromagnitniye-kontactory.html

26. Контакторы серии КПД : веб сайт URL www.kontaktor.su/kontaktori-kpd-ktk.html

27. GOST 12.0.003-74 “Occupational safety standards system. Dangerous and harmful production effects. Classification”

28. NPAOP 0.00-4.12-05 “Typical regulation of arrangement about training and occupational safety knowledge test”

29. GOST 12.1.030-81 (2001) «SSBT. Electric safety. Protective grounding, nulling»

30. ISO 9241-6:1999 “Ergonomic requirements for office work with visual display terminals (VDTs)”

31. DSANPIN 3.3.2.007-98 “State sanitary rules and regulations for working with visual display terminals of electronic computers”

32. DBN V.2.5-28:2018 "Engineering equipment of buildings and constructions. Natural and artificial lighting"

33. GOST 12.1.005-88 "Occupational safety standards system. General sanitary requirements for working zone air"

34. DSN 3.3.6.042-99 "Sanitary norms of microclimate of industrial premises"

35. DSANPIN 3.3.2.007-98 "State sanitary rules and regulations for work with visual display terminals of electronic computers"

36. DSN 3.3.6.037-99 “Sanitary standards of production noise, ultrasound and infrasound”

37. DSTU EN V.1.1-36:2016 “Determination of premises, houses and external installations classes according to blast-fire and fire safety”

38. DBN.1.1-7:2016 “Construction sites fire safety. General requirements.”

39. NAPB B.06.004-97 "The list of one-type intension objects, that must be equipped with automatic fire alarm and fire extinguishing systems"

40. DBN V.2.5-13-98 "Engineering equipment of houses and

buildings. Automatic fire alarm system for houses and buildings"

41. NAPB B.03.001-2004 "Typical norms for fire extinguishers"

42. DSTU EN 4297:2004 «Fire engines. Fire extinguishers technical maintenance. General technical regulations»