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INCREMENTAL INNOVATION METHODOLOGY THAT COMBINES COMPUTERIZED MODELLING AND SIMULATION WITH VALUE ANALYSIS AND ENGINEERING METHOD

BY

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Abstract. Current research responds to the need to add value to a product right from the conception phase and incrementally whenever the product's customers demand it. Thus, this paper presents a hybrid method of adding value to a single-phase asynchronous motor by combining computerized modelling and simulation of a single-phase asynchronous motor with an incremental innovation technique based on value analysis and engineering for functional optimization of this device. The methodology combines these two techniques to obtain a customer-oriented product with optimally dimensioned functions that correspond to the needs of the device's customers. The novelty of the work consists of the research methodology, which includes the application of functional analysis method during the design and redesign stages of a single-phase asynchronous motor.

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Keywords: computerized modelling and simulation, functional analysis, value analysis and engineering method, single-phase asynchronous motor.

1. Introduction

The current research is focused on a comparative analysis of various constructive variants of the rotor of a single-phase asynchronous motor. The positive characteristic of this type of motor is its ability to be powered with a single-phase supply at a frequency of 50-60 Hz, making them suitable for household appliances (Anthony *et al*., 2022). The negative characteristic of this type of motor is related to its efficiency in converting electrical energy into mechanical energy, which is much lower compared to three-phase motors (Diyoke and Ekwe, 2014).

Taking into account these two characteristics, the purpose of this study has been established as a comparative research between different constructive variants of rotors for single-phase asynchronous motors. Some changes in the parameters of the rotor in short circuit are possible without additional investments due to material costs. In other words, this research aims to find a possible optimal rotor design for parameters such as shape, inclination angle, and material type of the short-circuit bars, which has the same material and labor cost but at the same time provides a higher efficiency in converting electrical energy into mechanical energy (Ebrahim and Sweelm, 2022; Halina, *et al*., 2018).

The research methodology includes an incremental innovation analysis "human centered", which analyses customer/user satisfaction levels combined with a functional modeling of the motor in MotorCAD for the purpose of its redesign.

Redesigning a single-phase asynchronous motor may involve improvements in design, efficiency, performance, or adaptations to new application requirements. In such cases, some stages, such as prototype development and specification research, may be skipped, and the process can begin directly with the design and optimization of the new features (Whitman and Terry, 2022).

In the conclusion of the study, the performances of the two types of motors – the baseline and the redesigned one – are compared in terms of mechanical characteristics, power, efficiency, and currents.

2. Material and method

The methodology for creating a prototype of a single-phase asynchronous motor consists of a hybrid method - technical modelling and simulation (Buede and Miller, 2016) and an incremental innovation method "human-centred" (Hussain *et al*., 2022) - based on the functional analysis methodology applied to a single-phase asynchronous motor. Both methods are correlated to achieve a new asynchronous motor (Fig. 1).

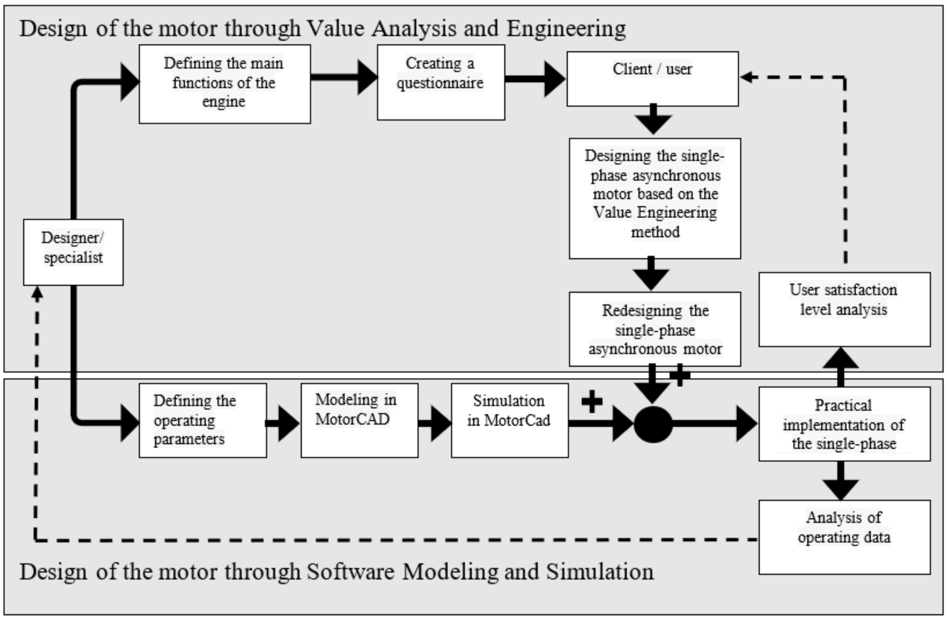


Fig. 1 – Design and redesign stages of a single-phase asynchronous motor.

The methodology for designing and redesigning a single-phase asynchronous motor (Fig. 1) begins with the designer/specialist defining the parameters of the single-phase asynchronous motor. It involves two techniques - one for modelling and simulating a single-phase asynchronous motor using the MotorCAD application and another oriented towards the client/user, which utilizes functional analysis from the value analysis and engineering method. The results are accumulated, and a new rotor design solution is chosen. The feedback process consists of two loops - one for analysing the user satisfaction level for the single-phase asynchronous motor with the new type of rotor and the other for analysing the operating data of the motor with the new type of rotor on the test bench.

3. Case Study: Single-phase asynchronous motor

The study involves a comparative analysis of the technical characteristics that can be obtained for a single-phase asynchronous motor based on the shape of the rotor slot and its inclination angle.

3.1. Defining the operating parameters of a single-phase asynchronous motor

For the study, a single-phase asynchronous motor used in a hydrophore is utilized, with the technical data presented in Table 1. It should be noted that the motor operates with an 8µF capacitor on the auxiliary phase to create a phase shift relative to the main phase. This capacitor is connected both during startup and throughout the motor's operation.

Table 1

Technical characteristics of the single-phase asynchronous motor

M [Nm]	P2 [W]	U [V]	I [A]	P1 [W]	Efficiency [%]
1.28	*300*	*230*	*2.89*	*663.7*	*45.2*

Where:
- M - motor torque
- P2 - mechanical power
- P1 - active power at the input
- U - voltage
- I - current

The motor has a starting capacitor of 8µF. Tests were conducted in the experimental setup (Fig. 2) to determine the technical characteristics of the motor with the rotor in its original construction variant.

Using the specialized LabView software, the following values are acquired for the following parameters: main phase current I1, auxiliary phase current I2, voltage U, motor speed, and motor torque tested.

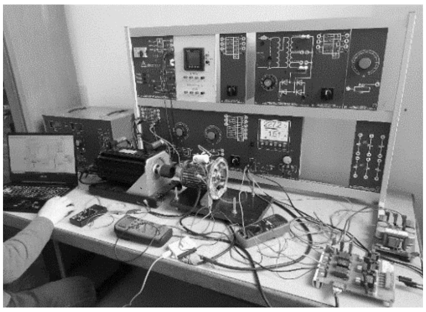


Fig.2 – Experimental setup.

3.2. Designing the single-phase asynchronous motor using Value Engineering analysis

The Value Engineering analysis method is an incremental innovation method for a product and service centred around the customer (Miles, 2015).

The customer is questioned about the main functions of the product, based on which the utility of each function is weighted in the total utility of the product. The utility weight is compared to the cost weight of each function, and the ratio of weights is referred to as the value ratio of an ideal product. Solutions are applied to optimize the sizing of the product functions (Longo *et al*., 2020).

The functions identified following the product analysis are:

• F1 – reliability.
• F2 – maintainability.
• F3 - resistance to mechanical agents.
• F4 - resistance to environmental factors.
• F5 - information carrying.
• F6 - the ability to connect to a standard 220 V, f=50 Hz power supply.
• F7 - ensuring electrical safety.
• F8 - ensuring thermal balance.
• F9 - transforming electrical energy into mechanical energy.
• F10 - developing high motor torque.

A questionary is applied to a sample of 20 potential real users of this device. The questionnaire contains one question for each function to be estimated, marked with a numerical value between 1 and 100 with increments of 5, according to the level of importance given by each respondent to the analyzed function (1 = not significant, 100 = utmost importance).

The results are summarized in Table 2.

Table 2
Centralized results of the questionnaire responses

No.	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Total	*1715*	*1120*	*1325*	*660*	*965*	*1765*	*1590*	*825*	*1675*	*1620*
Mean	*85.75*	*56*	*66.25*	*33*	*48.25*	*8825*	*79.5*	*41.25*	*83.75*	*81*
Weight pj	*12.93*	*8.45*	*9.99*	*4.98*	*7.28*	*13.31*	*11.99*	*6.22*	*12.63*	*12.22*
Order	*2*	*7*	*6*	*10*	*8*	*1*	*5*	*9*	*3*	*4*
Notes	*9*	*4*	*5*	*1*	*3*	*10*	*6*	*2*	*8*	*7*
Weight pj’	*16.36*	*7.27*	*9.09*	*1.82*	*5.45*	*18.18*	*10.91*	*3.64*	*14.55*	*12.73*

In Table 2, *Weight pj* represents the ratio of the average of each function to the total average. The functions are then arranged in ascending order based on their weights (in the *Ordine* line). The functions are noted according to the relation ($11\text{-}Ordine_j$), and *Weight pj'* represents the ratio of the function's grade to the sum of grades.

The technical sizing of the functions involves determining their utility. The utility of each function is calculated using the formula: Ui = pi * ui, where pi is the weight of the functions in the utility of the ideal product, and ui is the intrinsic utility of each function (Spiekermann and Winkler, 2020).

The following expressions have been proposed for the intrinsic utility of the motor functions:

F1 - reliability

Reliability represents the overall qualities of the single-phase asynchronous motor that determine its ability to function without defects within a given time interval and under certain conditions. The average working time until the first failure is 8000 hours. Considering that this interval of defect-free motor operation fully satisfies the user, we will note the intrinsic utility of this function u1 = 1.

F2 - maintainability

Maintainability is the property of the motor to be easily maintained and repaired. The average repair time of a single-phase asynchronous motor is 0.5 hours. Considering that this repair time fully satisfies the user, we will note the intrinsic utility of this function u2 = 1.

F3 - resistance to mechanical agents

The motor withstands shocks, vibrations, and impacts. Due to a lack of information about other mechanical agents, we will assume that the analyzed motor has an intrinsic utility for this function u3 = 1.

F4 - resistance to environmental factors

The motor is designed to operate in macroclimatic zones with temperate climate N, characterized by:

• Ambient temperature: -33°C to +40°C
• Relative humidity: max 80% at +20°C
• Altitude: max. 1000 m

Considering that compliance with these parameters fully satisfies the user, we will note the intrinsic utility of this function u4 = 1.

F5 - information carrying

The motor's nameplate indicates useful information about it. We consider the intrinsic utility of this function to be u5 = 1.

F6 - allows connection to a standard 220 V, f=50 Hz power supply

We consider the intrinsic utility of this function to be u6 = 1.

F7 - ensures electrical safety.

The motor's construction allows safe use without the risk of electric shock. We consider the intrinsic utility of this function to be u7 = 1.

F8 - ensures thermal balance.

The motor's operating temperature in load is within predetermined values. We consider the intrinsic utility of this function to be u8 = 1.

F9 - transforms electrical energy into mechanical energy.

The utility of this function is considered to be directly proportional to the ratio of active power to the apparent power of the motor. The intrinsic utility of this function is u9 = 0.6 (efficiency 59.35%).

F10 - develops high motor torque

This function represents the motor's capacity to develop the force required to rotate its moving parts. The torque the motor develops depends on the rotor's electric current and the excitation magnetic field. According to the responses to question number 11 in the questionnaire ("How satisfied are you with a torque of 1.28 Nm created by a single-phase asynchronous motor?"), the interviewees evaluated their satisfaction with the torque of 1.26 Nm with an average grade of 75.2. Therefore, we will consider the intrinsic utility of this function u10 = 0.75.

Analysis of grade distribution

Analyzing the distribution for each function (we apply statistical tests for evaluating grade distribution), it is observed that there is an approximately normal distribution for F1, F2, F3, F4, F5, F7, F8, and F9, and an approximately exponential distribution for F6 and F10. For functions with a normal distribution, the mean parameter is considered representative of the entire series.

Economic sizing of the functions

The economic sizing of the functions (Table 3, Table 4) of the single-phase asynchronous motor involves analyzing the product from the manufacturer's point of view, which requires determining the cost of each function (Hubka and Eder, 2012).

Table 3
Economic sizing - Kij [%]

Subassembly	Mat. cost	Labour cost	Total cost	Allocation by functions as % of the total cost									
	%	%	%	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Stator housing	*16.3*	*35.1*	*23.74*	*20*	*15*	*25*	*5*	*0*	*0*	*10*	*25*	*0*	*0*
Main winding	*41.3*	*19.1*	*32.61*	*2*	*0*	*0*	*2*	*0*	*0*	*0*	*0*	*35*	*61*
Auxiliary winding	*11.6*	*11.0*	*11.40*	*2*	*0*	*0*	*2*	*0*	*0*	*0*	*0*	*50*	*46*
Nameplate	*0.3*	*0.5*	*0.40*	*0*	*0*	*0*	*0*	*100*	*0*	*0*	*0*	*0*	*0*
Capacitor	*4.1*	*1.0*	*2.89*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*70*	*30*
Power supply cable	*3.9*	*1.0*	*2.77*	*0*	*0*	*0*	*0*	*0*	*100*	*0*	*0*	*0*	*0*
Bearings	*3.9*	*1.0*	*2.77*	*45*	*37*	*10*	*0*	*0*	*0*	*0*	*0*	*5*	*3*
Rotor cage	*11.1*	*3.0*	*7.91*	*10*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*30*	*60*
Laminations	*5.8*	*23.1*	*12.66*	*5*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*65*	*30*
Shaft	*1.4*	*5.0*	*2.85*	*40*	*60*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*

Table 4
Economic Sizing - Monetary Units

Subassembly	Mat. cost	Labour cost	Total cost	Allocation by functions in monetary units									
	u.b.	u.b.	u.b.	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Stator housing	*25.0*	*35*	*60.0*	*12*	*9.0*	*15*	*3.0*	*0.0*	*0.0*	*6.0*	*15*	*0.00*	*0.0*
Main winding	*63.4*	*19*	*82.4*	*1.6*	*0.0*	*0.0*	*1.6*	*0.0*	*0.0*	*0.0*	*0.0*	*28.8*	*50.3*
Auxiliary winding	*17.8*	*11*	*28.8*	*0.5*	*0.0*	*0.0*	*0.6*	*0.0*	*0.0*	*0.0*	*0.0*	*14.4*	*13.3*
Nameplate	*0.5*	*1*	*1.0*	*0.0*	*0.0*	*0.0*	*0.0*	*1.0*	*0.0*	*0.0*	*0.0*	*0.00*	*0.0*
Capacitor	*6.3*	*1*	*7.3*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*5.11*	*2.2*
Power supply cable	*6.0*	*1*	*7.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*7.0*	*0.0*	*0.0*	*0.00*	*0.0*
Bearings	*6.0*	*1*	*7.0*	*3.1*	*2.5*	*0.7*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.35*	*0.2*
Rotor cage	*17.0*	*3*	*20.0*	*2.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*6.00*	*12.0*
Core laminations	*9.0*	*23*	*32.0*	*1.6*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*20.8*	*9.60*
Shaft	*2.2*	*5*	*7.2*	*2.88*	*4.3*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.00*	*0.0*
Total cost Cj	*153.2*	*99.5*	*252.7*	*23.8*	*16*	*16*	*5.2*	*1.0*	*7.0*	*6.0*	*15*	*75.5*	*87.5*
Cost weight k_j	*60.63*	*39.3*	*100*	*9.44*	*6.3*	*6.2*	*2.1*	*0.4*	*2.8*	*2.4*	*5.9*	*29.8*	*34.6*

Systemic analysis of functions

In Table 5, the weights of each function in terms of cost and utility are centralized about the ideal product and the utility of each function is weighted by the realized product (Parnell *et al*., 2022).

Table 5
Systemic analysis of functions of the single-phase asynchronous motor, variant V1

Indicator	Total	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Cost weight kj	*100*	*9.44*	*6.30*	*6.21*	*2.07*	*0.40*	*2.77*	*2.37*	*5.94*	*29.88*	*34.3*
Utility weight pj	*100*	*12.93*	*8.45*	*9.99*	*4.98*	*7.28*	*13.3*	*11.99*	*6.22*	*12.63*	*12.2*
Utility Uj	*90*	*12.93*	*8.45*	*9.99*	*4.98*	*7.28*	*13.3*	*11.99*	*6.22*	*5.68*	*9.2*
Intrinsic utility u		*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*0.45*	*0.7*

The purpose of the systemic analysis of functions of the single-phase asynchronous motor is to identify functions that are economically oversized - functions whose costs are higher than their utility value.

We denote 'a' as the regression slope, calculated as $a = \frac{\sum k_j \cdot p_j}{\sum p_j^2}$.

Let S represent the sum of deviations of function sizes from optimally dimensioned values. A product is optimally dimensioned if S < 0.01 (Toporascu, 2023).

$$S = \sum_{1}^{n} (k_j - a \cdot p_j)^2$$

For the case where the utility weight is calculated based on survey responses, the following values are obtained: a = 1.0632 (corresponding to a regression line angle of 46.75 degrees), and the sum of squared deviations is S = 0.1086, which exceeds the threshold value of 0.01. The conclusion is that the product needs to be better balanced regarding the proportionality of its two dimensions (technical and economic) for the functions considered necessary for the single-phase asynchronous motor (Lupacescu, 2023).

The dimensioning of functions is graphically presented in Fig. 3.

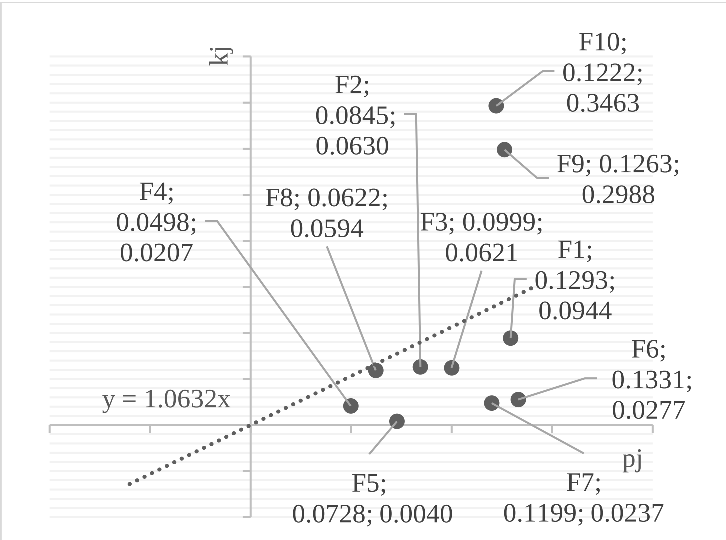


Fig. 3 – Systemic analysis using data from the statistical survey.

Following this analysis, we can draw the following conclusions (Lupacescu, 2023). The following functions are economically oversized (cost weight greater than utility weight): F9 - transforms electrical energy into mechanical energy and F10 - develops high torque.

The following functions are economically undersized (cost weight smaller than utility weight):
• F1 - is reliable.
• F2 - is maintainable.
• F3 - withstands mechanical agents.
• F4 - is resistant to environmental factors.
• F5 - carries information.
• F6 - allows connection to a standard 220 V, f=50 Hz power network.
• F7 - ensures electrical safety.
• F8 - ensures thermal balance is almost optimally dimensioned (the utility weight is approximately equal to the cost weight).

3.3. Modeling of the V1 motor in MotorCad

We create the model of the V1 motor (single-phase asynchronous motor) in the MotorCad software. It is necessary to know the geometrical dimensions of the V1 motor. The motor is disassembled to perform the necessary measurements.

In the next stage, the measured dimensions from the real V1 motor were entered into the MotorCad software. Thus, the virtual model of the V1 motor was created, which can be visualized from a radial perspective in Fig. 4a. After creating this model, the number of turns passing through each stator slot was calculated. Knowing the thickness of both the main and auxiliary winding turns, as well as the approximate section of the slots, the calculation showed that there are approximately 77 turns for the primary phase and about 154 turns for the auxiliary winding passing through each slot (Fig. 4b). Subsequently, the windings were placed in the slots, as shown in Fig. 4c (Lupacescu, 2023).

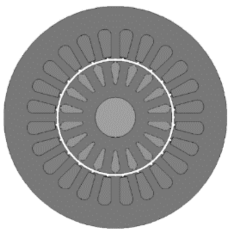


Fig. 4a – Radial perspective of the V1 motor in MotorCad.

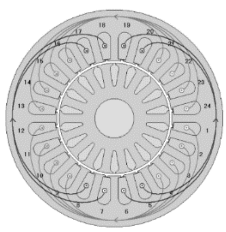


Fig. 4b – Arrangement of windings in slots.

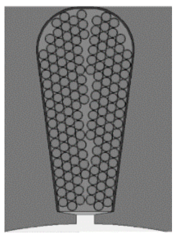


Fig. 4c – Configuration of turns in a slot.

Below are the graphs showing the data obtained from the simulation of the V1 motor's operation, modelled in MotorCad.

From the modelling, it can be observed that:

- The simulated motor efficiency is approximately 16% lower than the V1.

- The maximum power of the simulated motor is 300W (at a speed of approximately 2420 rpm) compared to 340W (at a speed of 2580 rpm) for the V1.
- At a load of 0.42 Nm, the simulated motor maintains its speed at approximately 2850 rpm, about 40 rpm less than the motor at the same load.
- At a load of 0.65 Nm, the simulated motor reaches 2760 rpm, about 80 rpm less than the motor.

The difference between the results obtained from the acquisition and the simulation is due to precision errors in measuring the slot fill factor, which was necessary for calculating the number of turns per slot. Additionally, no precise measurements were made for the stator slot area because accurate measurements would have damaged the windings.

Design and simulation in MotorCad using the new rotor construction variant

For designing the new rotor (version V2 of the motor), the original rotor dimensions were used, with only modifications made to the short-circuiting bar inclination, changing it from 27 degrees to 0 degrees and altering their shape (choosing a rectangular shape instead of pear-shaped). However, the same cross-section of the bars was maintained.

This technical solution was employed to optimally size the oversized functions (F9 - transforms electrical energy into mechanical energy, and F10 - develops high torque) by increasing the utility weights faster than the cost weights for these functions.

The new rotor can be seen in the V2 version of the motor, simulated in MotorCad, as shown in Fig. 5 (Lupacescu, 2023).

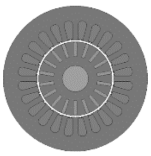


Fig. 5a – Radial perspective of the V2 motor in MotorCad.

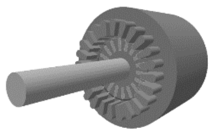


Fig. 5b – The 3D perspective of the V2 motor.

All the analyzed parameters - currents versus speed, efficiency versus speed, power versus speed, and mechanical characteristic - within the simulation of the V2 motor have higher values than the values of the same parameters for the V1 motor variant. From this, we can deduce that a rotor that uses the same amount of aluminum as in the original construction for the short-circuiting bars, with only changes in shape (from pear-shaped to rectangular) and the inclination angle, will offer higher performance compared to the V1 motor rotor.

Reconceptualization of the single-phase asynchronous motor

Therefore, the proposed variant for the reconceptualization of the product consists of acting on these two functions while maintaining the same costs. To increase the utility of functions F9 and F10, it is proposed to modify the construction variant of the rotor by changing the shape and inclination of the short-circuiting bars. Thus, instead of the first construction, variant V1 with pear-shaped short-circuiting bars inclined at 27 degrees, variant V2 is proposed, with rectangular-shaped bars and 0-degree inclination.

It is worth mentioning that both construction variants of the rotor use the same amount of aluminum for the short-circuiting bars, so the costs remain the same.

As a result of the modifications made during the reconceptualization of the initial product, a motor with a new rotor was designed, which has the characteristics shown in Table 6 (Lupacescu, 2023).

Table 6

Characteristics of the V2 version of the single-phase asynchronous motor

M_2 [Nm]	$P2_2$ [W]	U_2 [V]	I_2 [A]	$P1_2$ [W]	Efficiency [%]
1.33	*327.3*	*230*	*2.7*	*621.1*	*52.7*

Due to the modification of the efficiency and torque parameters, the intrinsic utility values of functions F9 and F10 will change as follows:

The intrinsic utility of function F9 will increase directly proportional to the increase in the efficiency of transforming electrical energy into mechanical energy, and therefore, it will take the value u9=0.53;

The intrinsic utility of function F10 will be calculated using the formula $\mathring{u}_9 = \frac{M_2}{M} \cdot u_9$=0.78.

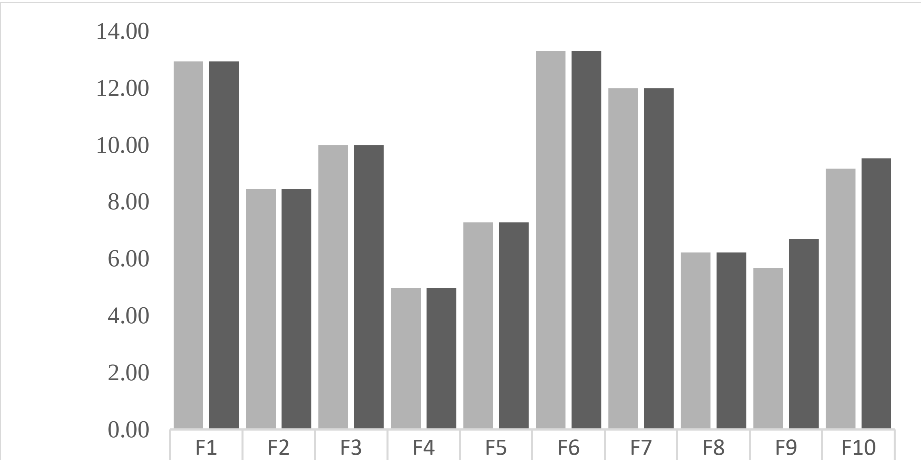
The systemic analysis for the V2 variant of the single-phase asynchronous motor is summarized in Table 7 (Lupacescu, 2023).

Table 7

Systemic analysis of functions of the single-phase asynchronous motor, variant V2

Indicator	Total	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Cost weight kj	*100.00*	*9.44*	*6.30*	*6.21*	*2.07*	*0.40*	*2.77*	*2.37*	*5.94*	*29.88*	*34.63*
Utility weight pj	*100.00*	*12.93*	*8.45*	*9.99*	*4.98*	*7.28*	*13.31*	*11.99*	*6.22*	*12.63*	*12.22*
Utility Uj	*91.38*	*12.93*	*8.45*	*9.99*	*4.98*	*7.28*	*13.31*	*11.99*	*6.22*	*6.69*	*9.53*
Intrinsic utility u		*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*0.53*	*0.78*

In Fig. 6, the utilities of the functions for the two asynchronous motors, V1 and V2, are presented through direct comparison.



	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Utility V1	12.93	8.45	9.99	4.98	7.28	13.31	11.99	6.22	5.68	9.16
Utility V2	12.93	8.45	9.99	4.98	7.28	13.31	11.99	6.22	6.69	9.53

Fig. 6 – Comparison of the utilities of the two motors, V1 (grey) and V2 (black) (Lupacescu, 2023).

Practical realization of the new rotor model

The creation of the rotor model for the V2 variant of the motor began with drawing a sheet metal model in AutoCAD, which was later used by an electroerosion cutting machine to produce the rotor laminations. Similarly, the short-circuiting rings were cut from aluminium using the same method.

The rotor shaft was created on a lathe, following the model of the original shaft, and the 18 bars were made from 2mm thick aluminium strips (this dimension was reached due to an error in the product characteristics description on a store's website). Additionally, two bearings, 6201 and 6202RS, were used.

In the next stage, the laminations were fixed on the shaft using a keyway, and then the short-circuiting bars were inserted into them. Aluminium rings were inserted at the ends.

Due to some objective reasons and failed attempts to weld the bars to the short-circuiting rings, the decision was made to create a mechanical connection between them. This method of establishing electrical contact between the bars and rings results in a high resistance in the rotor's electrical circuit, which inevitably leads to significant losses and low motor efficiency.

After the mechanical connections were made, the ends of the bars were straightened on a lathe to balance the rotor (Fig. 7).

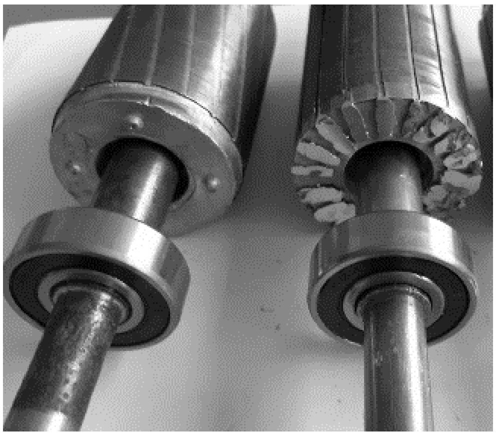


Fig. 7 – Visual comparison between the original rotor (left) and the rotor with rectangular aluminium bars (right) (Lupacescu, 2023).

The operating parameters of the V2 motor

After testing the V2 motor, the following results were obtained:

The startup time of the V2 motor is the same as the V1 motor, taking 1.15 seconds. However, it should be noted that in the case of V2, the current at startup on the auxiliary phase is higher, while on the main phase, it is significantly lower (maximum value of 3.5 A). This is due to the high resistance in the short-circuiting bars, and the nominal speed for this case is lower, approximately 2770 rpm.

Due to the structural peculiarities of the rotor, it is observed that the current waveform is not entirely sinusoidal and is slightly distorted. Compared with V1, this motor variant exhibits higher currents on both phases during idle operation.

At both the 0.42 Nm and 0.65 Nm loads, it can be observed that the currents for V2 are insignificantly higher than those of V1.

Comparing the results

The interpretation of the results obtained from the analysis of the technical characteristics of the V1 and V2 motor variants will be presented in the form of comparative graphs.

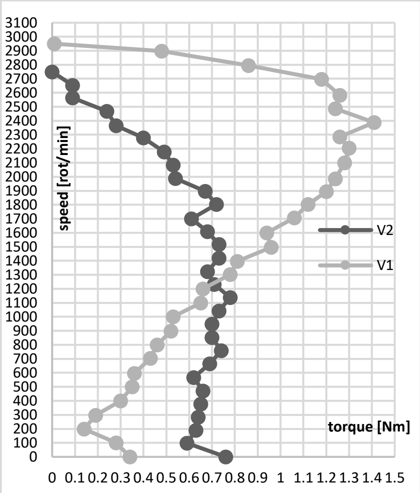


Fig. 8a – Speed=f(torque) for the V1 and V2 variants (Lupacescu, 2023).

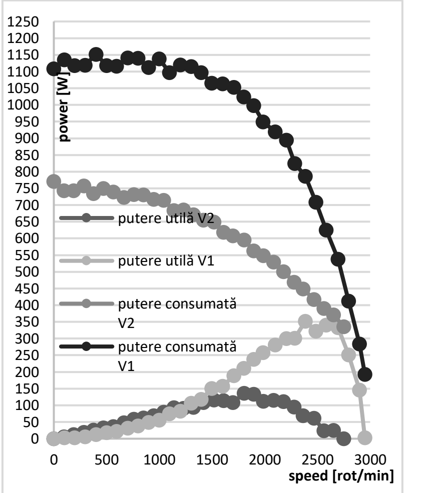


Fig. 8b – Power=f(speed) for the V1 and V2 variants (Lupacescu, 2023).

As shown in Fig. 8a, the V1 variant of the motor has a higher net torque than V2, especially at speeds above 1400 rpm, reaching a maximum torque of 1.4 Nm at 2400 rpm. It is also worth noting that the V2 variant exhibits a high starting torque due to the resistance created in place of the connection between the bars and the short-circuiting rings, which represents an advantage over V1. However, the V2 variant shows a very weak motor torque at high speeds. From Fig. 8b, we can deduce that the V1 variant consumes a large amount of electrical power at low speeds, resulting in low power. The difference between the values of the two powers becomes smaller as the speed increases, which will also be observed in Fig. 9. an on the efficiency comparison graph. Once again, it should be mentioned that the V2 variant exhibits better-starting characteristics, as indicated by this graph.

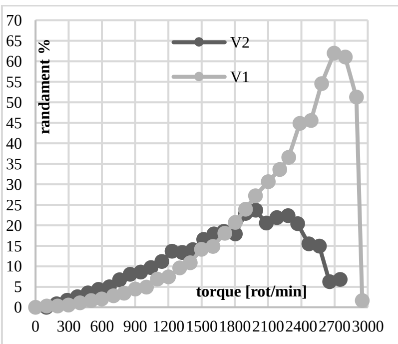


Fig. 9a – Efficiency comparison for the V1 and V2 variants (Lupacescu, 2023).

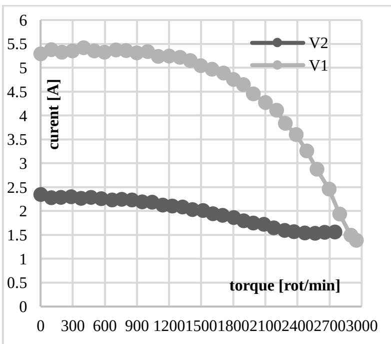


Fig. 9b – Current comparison for the V1 and V2 variants (Lupacescu, 2023).

From Fig. 9b, we can observe a decrease in the current absorbed from the network as the speed increases in the case of V1 and a relatively constant current consumption (2 - 2.4 A) in the case of V2.

4. Conclusions

The V2 variant of the single-phase asynchronous motor led to a clear understanding of the influence of the resistance between the bars and the short-circuiting rings on the motor's performance. This observation confirms the use of the method of starting by increasing the resistance in the rotor circuit.

Another important finding is that when modifying the cross-section of the rectangular bars, the shapes of the graphs representing the motor's operating parameters (according to data obtained from simulations) maintain their variations, showing only a translation on the Y-axis based on the increase or decrease in the cross-section of these bars. This conclusion confirms that the graphical differences were caused by the resistance between the rotor bars and the short-circuiting rings and not by the thickness of the bars. In other words, if the rotor bars of the V2 motor had been welded, the results would have been close to the simulated ones, and if these bars had a thickness of 2.5 mm instead of 2 mm, the results would have been closer to those presented in the work.

The combination of technical modelling and simulation methods with functional analysis in Value Analysis and Engineering represents a novelty, and, most importantly, it has led to the same technical solution for modifying the rotor of the single-phase asynchronous motor to improve its starting characteristics and increase its utility.

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METODOLOGIE DE INOVARE INCREMENTALĂ CE COMBINĂ MODELAREA ȘI SIMULAREA COMPUTERIZATĂ CU ANALIZA ȘI INGINERIA VALORII

(Rezumat)

Cercetarea curentă răspunde nevoii de a adăuga valoare unui produs chiar din faza de concepere și, incremental, de fiecare dată când clienții produsului sau serviciului o cer. Astfel, lucrarea prezintă o metoda hibridă de adăugare a unui plus valoare unui motor asincron monofazat prin îmbinarea modelării și simulării computerizate a unui motor asincron monofazat cu o tehnică de inovare incrementală bazată pe analiza și ingineria valorii pentru optimizarea funcțională a acestui dispozitiv. Noutatea cercetării este dată de metodologia ce îmbină aceste două tehnici pentru obținerea unui produs orientat către client/utilizator cu funcții optim dimensionate ce corespund nevoilor acestuia.