engineering proceedings

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# Graphical Dependencies and Mechanical Unit Selection for Driving a Work Machine †

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† Presented at the International Conference on Electronics, Engineering Physics and Earth Science (EEPES 2025), Alexandroupolis, Greece, 18–20 June 2025.

**Abstract**

The machine unit design for driving a specific work machine is a complex process, in which factors such as power machine type, power transmission drives, total efficiency coefficient, and total gear ratio determine an accurate model for calculating the drive. The correct choice of the above-described factors will lead to the construction of a machine unit with high performance while meeting the requirements of the client.

**Keywords:** electric motor; gear ratio; reducer; coupling; efficiency coefficient; dimensions; graph; belt drive; chain gear drive; gears; worm drive

## 1. Introduction

The power transmission drive design of a given working machine in general mechanical engineering (belt conveyor, press, saw, elevator, pump, etc.) [1–4] in most cases begins with the required parameters such as power and revolutions per minute of the working machine. This, in turn, significantly limits the design activity and makes the task difficult to solve [5–8]. To facilitate the solution of this task, a method for selecting a machine unit (Figure 1) through graphical dependencies between the rotation frequency of the electric motor rotor, the weight and length of the electric motor, the total efficiency coefficient for the mechanical system, the total gear ratio of the drive, and the overall dimensions of the power machine are examined in this report [9]. The dependencies are derived separately:

- $G = G(P)$ : electric motor mass as a function of its power—for motors with 750, 1000, 1500, and 3000 [rev/min];
- $L = L(P)$ : the length of the electric motor as a function of its power—for motors with 750, 1000, 1500, and 3000 [rev/min];
- $U = U(SMD)$ : the total gear ratio of the drive as a function of the type of mechanical system;
- $\eta = \eta(SMD)$ the total efficiency coefficient of the drive as a function of the type of mechanical system.

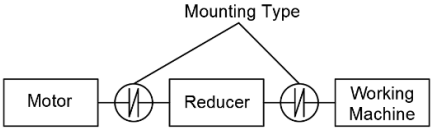



**Figure 1.** Machine unit.

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Academic Editor: Grigor Mihaylov

Published: 15 September 2025

**Citation:** Tenev, S.I. Graphical Dependencies and Mechanical Unit Selection for Driving a Work Machine. *Eng. Proc.* **2025**, *104*, 95. https://doi.org/10.3390/engproc2025104095

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When designing the machine unit, issues related to the selection of an electric motor are discussed, such as whether it will be from the group of 750, 1000, 1500, and 3000 rpm motors [10,11]; the selection of the machine unit mounting type, such as whether it will be a "Coupling" [12–14], "Belt drive", "Chain drive", etc.; and the selection of a gear reducer, such as whether it will be a "Single stage cylindrical reducer", "Two stage bevel-cylindrical reducer, "Worm reducer", etc. [15,16]. All these questions are answered when considering what gear ratio is required and what will be achieved with the individual unit selection. Along with the above, the following issues are also discussed: what efficiency coefficient will be obtained when choosing the drive and what size of the electric motor will be suitable to use in the system. Last but not least, the size of the selected gear reducer is monitored.

## 2. Materials and Methods

In some cases, the design of a machine unit can begin with the selection of an electric motor. To form the graphic dimensional dependencies of the electric motors, data for three-phase asynchronous motors from the groups of 750, 1000, 1500, and 3000 rpm motors are used [17]. The data for the length and weight of the electric motor are taken from company catalogs of Bulgarian manufacturers. The parameters can be changed depending on the machine availability on the relevant market, but the methodology for selecting a machine unit for driving a working machine remains the same.

Figure 2 shows the relationship $G = G(P)$, where $G$ is the mass and $P$ is the engine power. To better illustrate the above relationship, engines up to 20 kW are presented.

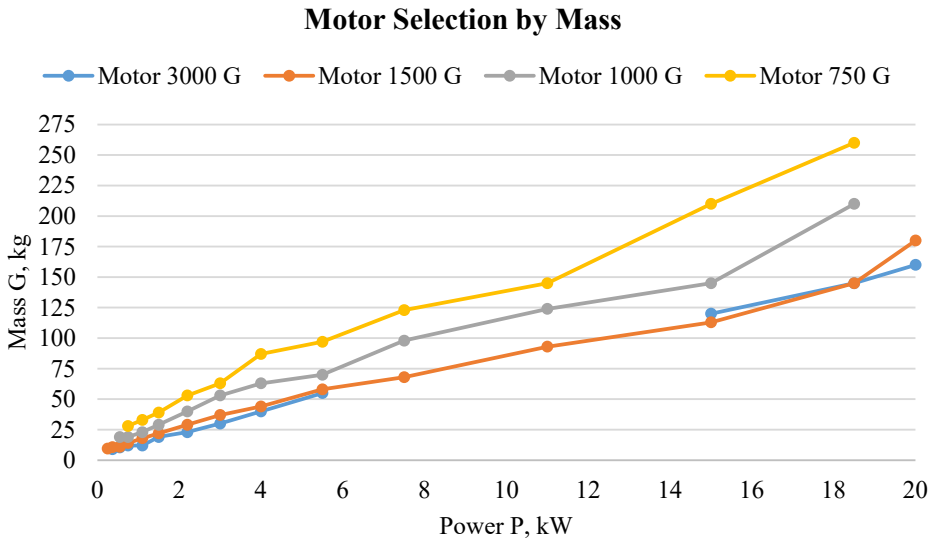



**Figure 2.** Motor selection based on the mass.

The next relationship characterizing the overall dimensions of electric motors is $L = L(P)$, where $L$ is the length of the motor. The relationship is presented again for motors with 750, 1000, 1500, and 3000 rev/min rotation frequency and up to 20 kW power (Figure 3).

One of the main requirements when choosing a power transmission drive is the minimum size of the machine unit [18]. This, in turn, forces the designer to carefully select an electric motor based on size and weight. The following graph (Figure 4) summarizes the dependence of the weight and length of the electric motor in relation to its power and speed.

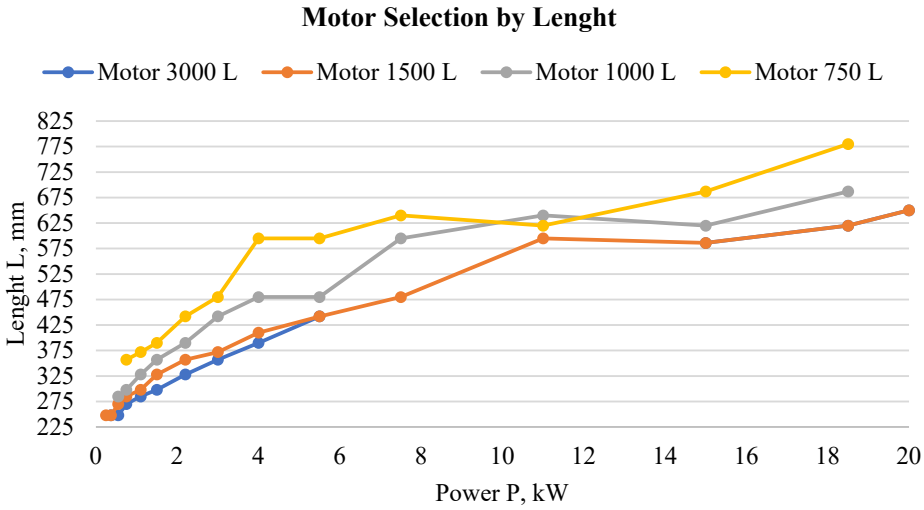



**Figure 3.** Motor selection based on the length.

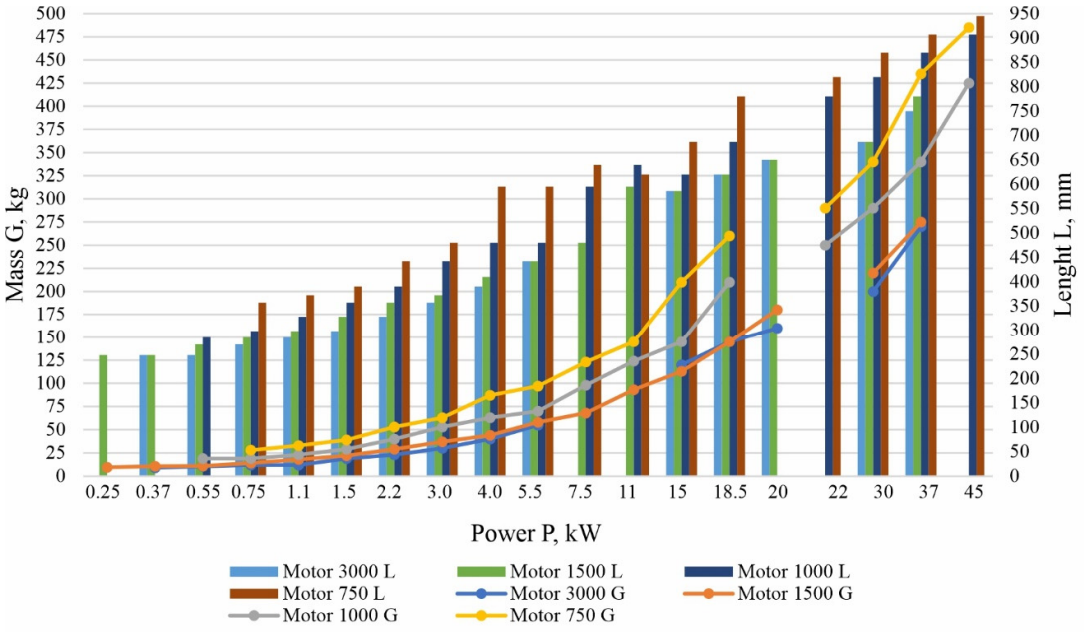



**Figure 4.** Motor selection.

The first drive that will be considered is the coupling part. Here, a choice must be made between a coupling, VBD, TBD, CGD, ECGD, or EBGD [19]. The choice comes down to the following: what efficiency factor will be realized, what gear ratio is required, and what overall dimensions the connection link part has. The overall dimensions of the coupling part are a relative value since the location of this unit is individual for each project (e.g., the overall dimensions of the unit may remain the same when choosing a coupling or belt drive). For this reason, this parameter will not be considered.

Gear ratio data of the mounting type are shown in Table 1, including their efficiency coefficients with average values from the specified ranges in reference books like "The Design of Machine Elements" [20–22].

To select the next drive, which should reduce the speed and increase the torque for the working machine, a decision is made as to "what gear reducer to use" [23].

Table 2 shows the main gear reducer parameters that are most commonly used in mechanical engineering. The data present the parameters $U_r$—the gear reducer ratio and efficiency coefficient, the latter being an average value from the specified range.

**Table 1.** The ratio, dimension coefficient, and efficiency factor of the connecting link.

| № | Connecting Link | Min Ratio | Max Ratio | Efficiency Factor |
|---|---|---|---|---|
| 1. | Coupling | 1 | 1 | 0.98 |
| 2. | V-belt Drive (VBD) | 2 | 7 | 0.955 |
| 3. | Toothed Belt Drive (TBD) | 2 | 12 | 0.95 |
| 4. | Chain Gear Drive (CGD) | 2 | 8 | 0.93 |
| 5. | External Cylindrical Gear Drive (ECGD) | 3 | 10 | 0.94 |
| 6. | External Bevel Gear Drive (EBGD) | 2 | 6 | 0.93 |

**Table 2.** The ratio and efficiency factor of gear reducers.

| Gear Reducer | Min Ratio | Max Ratio | Efficiency Factor |
|---|---|---|---|
| Single-Stage Cylindrical Reducer ($CR^{I}$) | 1.25 | 5.6 | 0.95 |
| Double-Stage Cylindrical Reducer ($CR^{II}$) | 6.3 | 28 | 0.91 |
| Triple-Stage Cylindrical Reducer ($CR^{III}$) | 22.4 | 112 | 0.88 |
| Single-Stage Bavel Reducer ($BR^{I}$) | 2 | 6 | 0.94 |
| Double-Stage Bevel Cylindrical Reducer ($BCR^{II}$) | 5 | 14 | 0.9 |
| Triple-Stage Bevel Cylindrical Reducer ($BCR^{III}$) | 12.5 | 80.9 | 0.87 |
| Single-Stage Worm Reducer ($WCR^{I}$) | 10 | 60 | 0.66 |
| Double-Stage Worm Cylindrical Reducer ($WCR^{II}$) | 50 | 400 | 0.63 |

Because the efficiency coefficient of power transmission drives is $\eta_m = \eta_c.\eta_{md}$ and the gear ratio is $U_m = U_c.U_r$, graphic relations $\eta = \eta(SMD)$ and $U = U(SMD)$ take on the form shown in Figures 5 and 6.

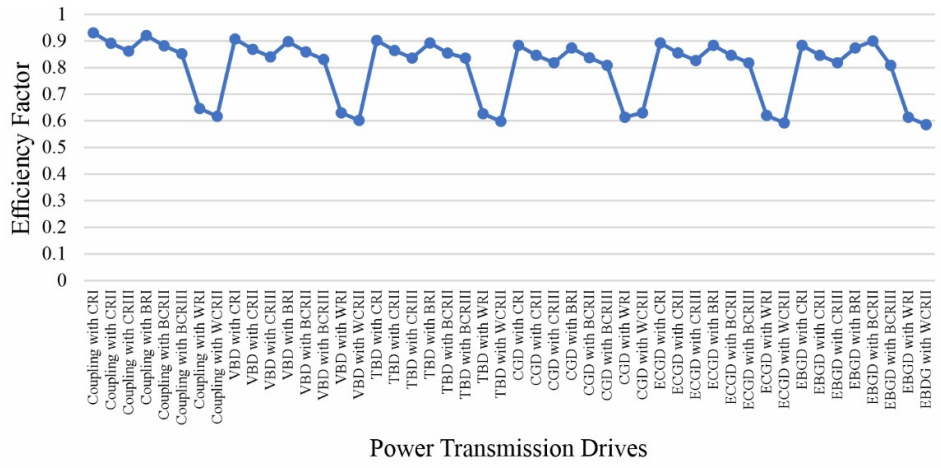



**Figure 5.** Power transmission drives selection based on EF.

The bar graph in Figure 6 presents the gear ratio of various power transmission drives used in mechanical engineering. The maximum limit for gear ratio is 100 to better illustrate the relationship.

The graphical dependencies of Figures 5 and 6 are interconnected with respect to the choice of a power transmission drive of a working machine. However, Figure 7 (presenting the summarized results) clearly shows the relationship between the most important parameters for a machine unit, namely, the power transmission drives efficiency and its gear ratio.

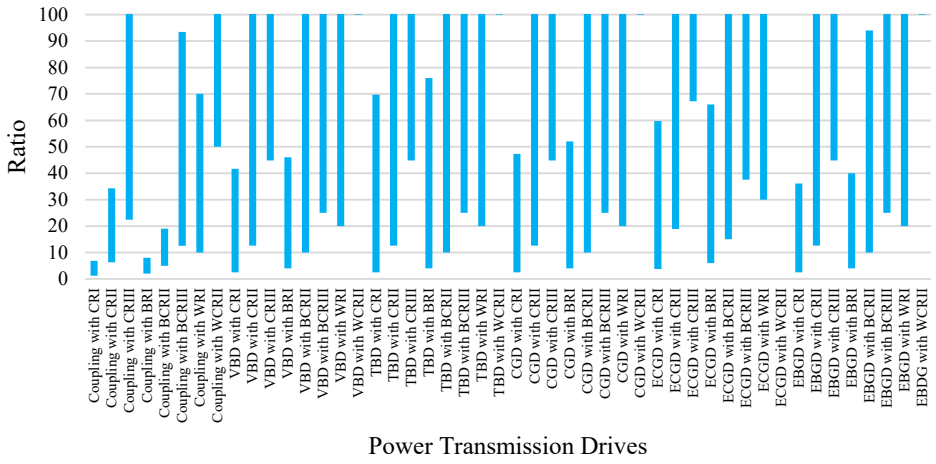



**Figure 6.** Power transmission drives selection based on the ratio.

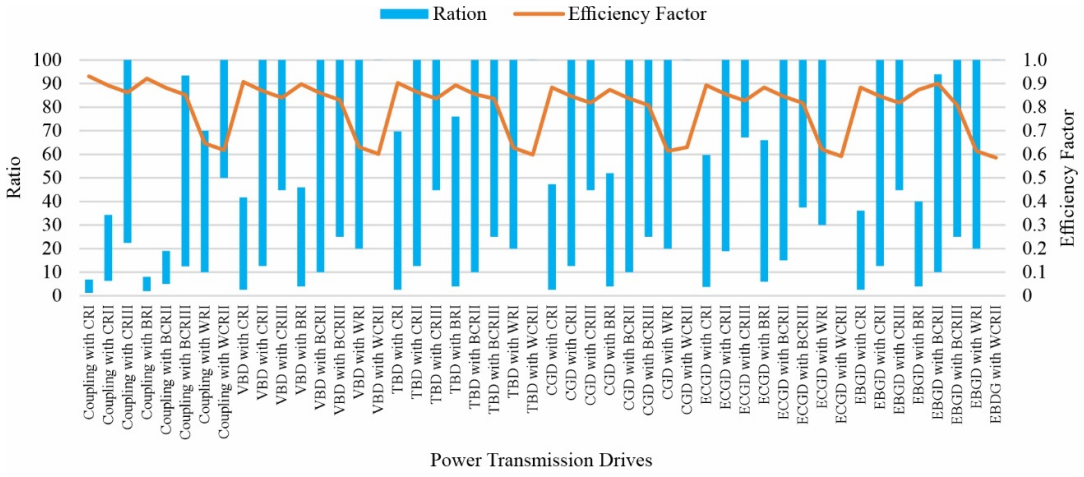



**Figure 7.** Dependencies of power transmission drives—the efficiency factor and ratio.

Given the above, an example of a graphical selection methodology of a power transmission drive for a working machine can be provided.

Example: Company "X", a leading manufacturer of coffee machines, wishes to increase its production activity by creating a new assembly line with maximum productivity for a new model of coffee machine. The new conveyor belt must be powered with $P_{new} = 3000$ W and provided with a roll rotation speed $n_{new} = 100$ rev/min.

Solution: From the given requirements for high productivity of company "X", a preliminary assessment of the effectiveness of the system should be made. The graph in Figure 5 shows that a coupling with CRI (EC $- \eta_{CCRI} = 0.93$) and a coupling with BRI (EC $- \eta_{CBRI} = 0.922$) have the highest efficiency. However, we should check whether their respective gear ratios will cover the required ratio of the revolutions of the electric motor and the working machine. The rotation speed ratio of the shafts is determined by the selected electric motor. The electric motor will be selected based on the minimum power.

$$P_{min^i} = \frac{P_{new}}{\eta_i} \text{W} \tag{1}$$

where $P_{min^i}$ is the minimal power of the new conveyor belt, and $\eta_i$ is EC of the power transmission drives, but in this specific case it is $\eta_{CCRI}$ and $\eta_{CBRI}$. From (1), minimal power is determined:

$$P_{min^1} = \frac{P_{new}}{\eta_{CCRI}} = \frac{3000}{0.93} = 3225.80\text{W} \tag{2}$$

$$P_{min^2} = \frac{P_{new}}{\eta_{CBRI}} = \frac{3000}{0.92} = 3260.87\text{W} \quad (3)$$

According to the calculations above, the most suitable electric motor for the working machine (conveyor belt) is the next largest in power from the minimum $P_{min^1}$ and $P_{min^2}$, namely, 4000 W.

From the graph in Figure 4, we preliminarily choose to check the required gear ratio with electric motors from the 3000 and 1500 rpm motor groups since they are the smallest in terms of weight and overall dimensions. The gear ratios in both cases are as follows:

$$U_1 = \frac{3000}{n_{new}} = \frac{3000}{100} = 30 \quad (4)$$

$$U_2 = \frac{1500}{n_{new}} = \frac{1500}{100} = 15 \quad (5)$$

where $U_1$ is the gear ratio with 3000 rpm of the motor and $U_2$ is the gear ratio with 1500 rpm of the motor.

The gear ratios (4) and (5) are plotted on the graph in Figure 7 to determine whether the coupling with CRI and the coupling with BRI can provide this relationship. The analysis shows that the initial choice of power transmission drives is NOT suitable, but it is also seen from the graph that the next higher efficiency power transmission drive is suitable for achieving both gear ratios, which is VBD with CRI ($\eta_{VBDCRI} = 0.91$).

## 3. Conclusions

The graphical selection method of a machine unit, used above, determines a quick and relatively accurate design solution for a working machine. With the help of two graphs and two preliminary calculations, a decision was made to select a machine unit that will meet the requirements for the necessary power and transmission ratio while, at the same time, meeting the condition for maximum productivity in terms of the achieved efficiency.

The summarized graphs in Figures 4 and 7 are created based on the data collected from Bulgarian manufacturers of "Gear Reducers" and "Electric Motors" and give a clear picture of the parameters of overall dimensions, mass, gear ratio, and efficiency. In the same way, information on the overall dimensions and mass of the gear reducer and the mounting type can be applied in the present methodology. This way, the choice of the power transmission drives will be confirmed or refined for the relevant requirements of the "Contracting company".

**Funding:** The paper was partially funded by NP7/2025 (TUV internal project funded by national budget). The author thanks colleagues from the university for their assistance.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Informed consent was obtained from the study participant.

**Data Availability Statement:** The data presented in this study are available upon request from the corresponding author.

**Conflicts of Interest:** The author declare no conflicts of interest.

## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| VBD | V-belt drive |
| TBD | Toothed belt drive |
| CGD | Chain gear drive |
| ECGD | External Cylindrical Gear Drive |

| | |
|---|---|
| EBGD | External Bevel Gear Drive |
| $CR^{I}$ | Single Stage Cylindrical Reducer |
| $CR^{II}$ | Double Stage Cylindrical Reducer |
| $CR^{III}$ | Triple Stage Cylindrical Reducer |
| $BR^{I}$ | Single Stage Bavel Reducer |
| $BCR^{II}$ | Double Stage Bevel Cylindrical Reducer |
| $BCR^{III}$ | Triple Stage Bevel Cylindrical Reducer |
| $WR^{I}$ | Single Stage Worm Reducer |
| $WCR^{II}$ | Double Stage Worm Cylindrical Reducer |
| EF | Efficiency Factor |

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