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The Influence of Asymmetric Load Distribution on V-Belt and Pulley Transmission in Belt Conveyor Systems

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Abstract

The assembly of the belt conveyor system conforms to the design drawings, measuring 3 m x 30 cm in length and 70 cm in height, made of steel (Figure 2). Belt conveyor performance depends on the uniformity of load distribution along the belt. Applications are primarily in industrial, retail, and airport environments. Space constraints often lead to asymmetric loading, which can alter contact pressure and increase belt misalignment, affecting the performance of the V-belt and pulleys in the belt conveyor system. Many studies have addressed belt tension regulation, pulley design, and material durability; however, few have specifically examined the effect of asymmetric loads on slip behavior, creating a knowledge gap in understanding the dynamic response of belt-pulley transmission systems. The method used was experimental testing, supported by theoretical torque measurements of the slip magnitude of the V-belt and pulley. Testing was performed by shifting the load to the left or right side of the belt, and the pulley speed was measured using a PLC-based system integrated with an inverter and HMI. The motor speed was set at 5 Hz and 8 Hz in the inverter. For symmetrical and asymmetrical load conditions, the pulley rotation output was read by the HMI in rpm, while the PLC functioned as the inverter and HMI controller. The results showed that for symmetrical and asymmetrical loads at a frequency of 8 Hz, the slip value tended to be lower than at a frequency of 5 Hz with a loading duration of 10 kg, starting from 20 kg to 60 kg. The increase in slip value with increasing load for symmetrical loads was lower when compared to asymmetrical loads, as shown in Figure 4 for symmetrical loads, and Figure 5 for asymmetrical loads. These findings provide important practical insights for optimizing conveyor systems operating under symmetrical loading conditions to reduce the increase in slip in belt conveyor systems.

Keywords: belt conveyor; symmetrical load; asymmetrical load; pulley slippage; transmission efficiency

Abstrak

Perakitan sistem belt conveyor telah sesuai dengan gambar desain, sepanjang 3 m x 30 cm, dan tinggi 70 cm berbahan baja, gambar 2. Kinerja belt conveyor bergantung pada keseragaman distribusi beban sepanjang belt. Dalam aplikasi terutama di lingkungan industri, retail, dan bandara. Keterbatasan ruang sering menimbukan pembebanan tidak simetris, sehingga beban yang tidak merata dapat mengubah tekanan kontak dan meningkatkan ketidaksejajaran belt yang mempengaruhi kinerja sabuk V dan pulley dalam sistem belt konveyor. Banyak penelitian telah membahas pengaturan tegangan belt, desain pulley, dan ketahanan material, hanya sedikit studi secara khusus meneliti pengaruh beban asimetris terhadap perilaku slip, sehingga menimbulkan celah pengetahuan dalam memahami respons dinamis sistem transmisi belt–pulley. Metode yang digunakan adalah pengujian eksperimenta, didukung dengan perhitungan teoritis besarnya slip pada sabuk V dan pulley. Rangkaian pengujian dilakukan dengan menggeser beban ke sisi kiri atau kanan belt, dan kecepatan pulley diukur menggunakan sistem berbasis PLC yang terintegrasi dengan inverter dan HMI. Kecepatan motor diseting pada frekuensi 5 Hz dan 8 Hz di inverter, untuk kondisi beban simetris dan asimetris, pembacaan output putaran pulley terbaca oleh HMI dalam satuan rpm, sedangkan PLC berfungsi sebagai pengotrol keja inverter dan HMI. Hasil penelitian menunjukkan, untuk beban simetris dan asimetris pada frekwensi 8 Hz, kecendrung nilai slip lebih rendah dari frekwensi 5 Hz dengan pembebanan berdurasi 10 kg, dimulai dari 20 kg s/d 60 kg, peningkatan nilai slip dengan penambahan beban pada beban simetris lebih rendah jika dibandingkan dengan beban asimetris, terlihat pada gambar 4 untuk beban simetris, dan gambar 5 untuk beban asimetris. Temuan ini memberikan wawasan praktis yang penting untuk mengoptimalkan sistem conveyor yang beroperasi pada kondisi pembebanan yang simetris guna mengurangi peningkatan slip lebih tinggi pada sistem belt conveyor.

Kata kunci: belt conveyor; beban simetris; beban tidak simetris; slip pulley; efisiensi transmisi

1. Introduction

Power transmission systems are essential components in mechanical processes, transferring energy from a driving source to a driven element. One of the most widely used transmission systems in industrial applications is the pulley and belt system, which offers advantages such as simple construction with high tensile strength, low cost, and ease of maintenance.

Under ideal conditions, the load distribution in a conveyor belt system is expected to be symmetrical, allowing for a balanced distribution of tension on the pulleys. However, in practice, uneven and unbalanced load distribution often occurs due to material buildup on one side of the conveyor belt and material asymmetry in the conveyor belt. This can lead to an imbalance in tension on the tight and loose sides of the belt, potentially leading to slippage and reducing transmission efficiency.

Extensive research has been conducted to improve the performance of these systems. For example, a study by Liu showed that the elasticity of the belt material significantly affects power loss, while Zhang examined the relationship between rotational speed and heat generation in V-belts. Furthermore, recent experimental research has focused on the use of sensors to detect early slippage in high-speed turbines [2]. However, despite these advances, a critical gap in the literature exists regarding slip behavior in systems characterized by relatively long center distances. Most existing studies utilize compact experimental setups, which do not account for the increased belt slack and dynamic instability inherent in long-span transmissions. In many small-scale industries, these long-span setups are common, but technical guidance for minimizing slip-related energy losses remains scarce [3].

Belt conveyors are a widely used material transportation tool in industries, department stores, airports, and other departments. Belt conveyors operate continuously, effectively, and efficiently, with relatively low operating costs. They are simple and easy to operate, and their construction is simple and easy to operate [4].

Engineering drawings are crucial because they serve as a reference for fabrication and assembly. The relationship between each component is clearly and systematically defined, and the assembly process is closely aligned with the engineering drawings, ensuring the efficiency of the machine's operation.

V-type pulleys and belts are transmission devices used to drive belt conveyor systems. This system transmits motor power to the pulleys, enabling the belt conveyor to move. Ideally, the load distribution on a belt conveyor is symmetrical. However, in practice, asymmetrical loads often arise due to uneven material accumulation, which can affect the overall effectiveness of the belt conveyor [5].

Reading the motor rotation in rpm on the drive pulley and the one whose driver uses a Programmable Logic Controller (PLC) based control system integrated with an Inverter and Human Machine Interface (HMI) system, aims to obtain motor speed data on the drive pulley and the moving pulley in real time and accurately, especially on the belt conveyor system. And for the pulley slip value will be calculated with a mathematical equation [6].

This study aims to analyze the effect of asymmetric load distribution on the amount of slip caused by pulley and belt transmissions and their impact on the performance of belt conveyor systems. By quantitatively understanding these characteristics, the results are expected to provide practical technical recommendations for improving transmission efficiency and extending service life in the national manufacturing sector [7].

2. Material and Method

To facilitate the research process, the methodology of this study is presented in the form of a flowchart, as shown in **Figure 1**.

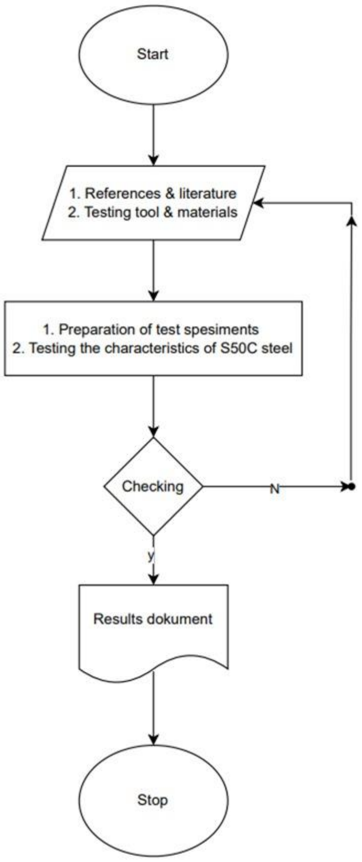

Figure 1. Flowchart of the belt conveyor system design

The research employed an experimental method aimed at investigating the effect of asymmetric loading on slippage between the pulley and a V-belt transmission system [8].

2.1 Equipment and Materials

a. Equipment

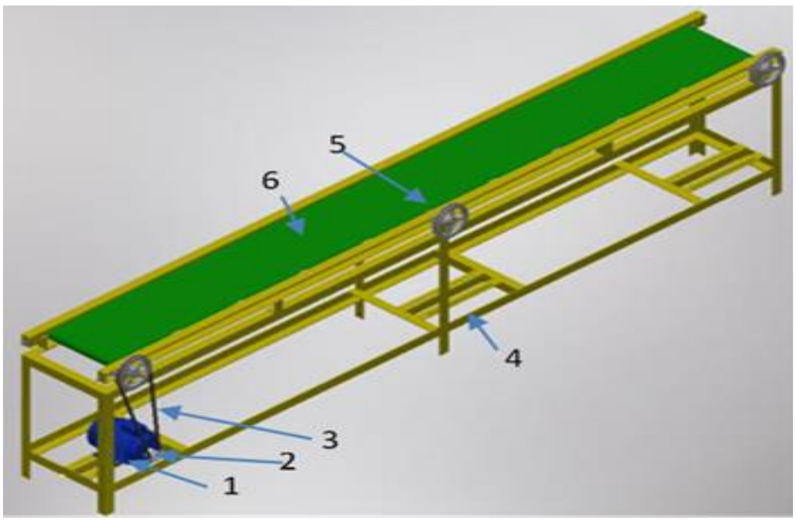

Figure 2. Belt conveyor transportation system

The experimental arrangement of the conveyor belt transport system consists of an electric motor as a driving source, using a V-belt and pulley transmission system, the rotation of the motor shaft and the drive pulley is transmitted to the moving pulley shaft, the conveyor belt movement is also supported by a drive roll and several support rolls to maintain the stability of the belt movement. The conveyor belt system is also illustrated in figure 2. While the specifications of each component can be seen in Table 1

Table 1. Specifications of the belt conveyor transportation system

No	Component	Specification	Quantity
1	Induction motor	3 Phase, ¾ HP	1
2	Small pulley	2 inch	3
3	V-belt	A1	1
4	Frame structure	3,20 x 45 x 65 cm	1
5	Large pulley	6 inch	3
6	Conveyor belt	3 m x 30 cm	1

Data collection during the experiment was supported by a motor control system consisting of 3 main components, namely an inverter (VFD/Variable Frequency Drive), PLC (Programmable logic controller), and HMI (Human machine Interface), as shown in Figure 3. The inverter as a motor speed controller is connected to the drive motor using an encoder, while the PLC functions as the brain of the system that gives commands to the inverter for start/stop functions and speed settings in frequency units (Hz), the PLC also functions to process data to be sent to the HMI in the rpm reading output.

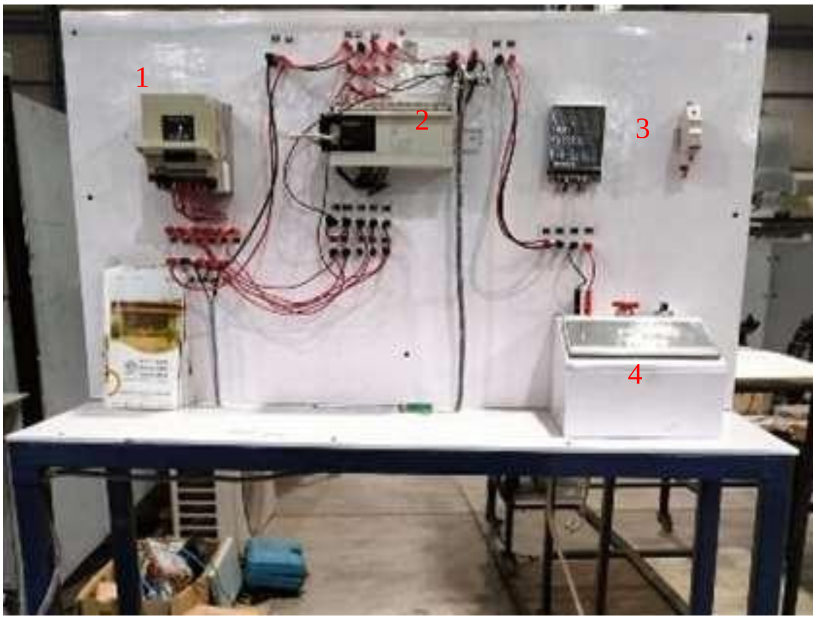

Figure 3. Motor control system using PLC

Table 2. Specifications of the PLC-based control system

No	Component	Specification	Quantity
1	Iverter	3 Phase, 1 HP	1
2	PLC	FX3U-24MR	1
3	Power suply	220AC-24DC	1
4	HMI	Wintek6070i	1
5	Encoder Omron	E6B2-CWZ6C	2

b. Materials

The materials used in the experimental tests consisted of solid steel blocks placed in containers. The applied load ranged from 20 kg to 60 kg, with increments of 10 kg.

2.2 Testing Procedure

The experiments were conducted using two loading configurations: symmetric loading and asymmetric loading. In the asymmetric configuration, the load was shifted from the center position either to the left or right by 20 mm, and 30 mm. The rotational speed of the system was controlled using the PLC by setting two frequency levels, namely 5 Hz and 8 Hz. For each speed condition, the load was varied from 20 kg to 60 kg in increments of 10 kg.

Pulley slippage was analyzed based on both theoretical calculations and actual measurement data, using the following equations [9], [10]:

$$Slip(\%) = \frac{n_{theoretical} - n_{actual}}{n_{theoretical}} x100\% \quad (1)$$

$$\pi . d_1 . n_1 = \pi . d_2 . n_{theretical} \quad \rightarrow \quad n_{theretical} = \frac{d_1}{d_2} n_1 \quad (no - slip\ speed) \quad (2)$$

$$V = \frac{\pi . d . n}{60} \quad (3)$$

Where:

$n = rotational\ speed\ (rpm)$; $V = linear\ velocity\ (m/s)$

$d_{1\ and}\ d_2 = diameters\ of\ driving\ and\ driven\ pulleys\ (m)$

The friction force between the rotating pulley and the belt can also be calculated using the following equation:

$$friction\ force = \mu . n \quad (4)$$

Where:

$\mu = coefficient\ of\ friction\ \left(\frac{N}{rpm}\right)$; $n = pulley\ rotation\ (rpm)$ Based on the Euler–Eytelwein equation, the relationship between the tight side and slack side of the belt on the pulley is expressed as:

$$\frac{T_1}{T_2} = e^{\mu\theta} \quad (5)$$

Where:

$T_1 = tight - side\ tension\ (N)$; $T_2 = slack - side\ tension\ (N)$; $\theta = belt\ wrap\ angle$ (°)

3. Results and Discussion

3.1 Experimental Results

experimental results of the driving pulley speed and driven pulley speed under various loading conditions, starting from symmetric load positions to asymmetric load positions, are presented in Tables 3 and 4, to the asymmetrical loading position, presented in table 5 and 6. In table 3, with a duration of increasing the load by 10 kg for symmetrical loading from 20 kg to 60 kg with a motor speed of 5 Hz, if calculated based on the average value, overall with the addition of a load of 10 kg there is a decrease of 11% from the lowest load, namely 20 kg.

Table 3. Symmetric load position with Motor speed of frequency 5 Hz

No	m(kg)	Motor (rpm)	Pulley (rpm) teori	Pulley (rpm) actual	Slip h%
1	20	119,5	39,8	38	4,60251
2	30	117,5	39,2	37,5	4,255319
3	40	118	39,3	38	3,389831
4	50	117	39,0	37,5	3,846154
5	60	116	38,7	37	4,310345

Table 4. Symmetric load position with Motor speed of frequency 8 Hz

No	m(kg)	Nmotor (rpm)	Npully (rpm) Theoretical	Npully (rpm) actual	Slip (%)
1	20	121	40,3	39	3,3
2	30	120,5	40,2	38,5	4,1
3	40	120	40,0	38	5,0
4	50	120	40,0	38	5,0
5	60	118	39,3	38	3,4

In table 4, with a duration of increasing the load by 10 kg for symmetrical loading from 20 kg to 60 kg with a motor speed of 8 Hz, if calculated based on the average value, overall with the addition of a load of 10 kg there is an increase of 26% from the lowest load of 20 kg.

Table 5. Asymmetric load position (30 mm offset) with Motor speed of frequency 5 Hz

No	m(kg)	Nmotor (rpm)	Npully (rpm) Theoretical	Npully (rpm) actual	Slip (%)
1	20	121	40,3	39	3,3
2	30	120,5	40,2	38,5	4,1
3	40	120	40,0	38	5,0
4	50	120	40,0	38	5,0
5	60	118	39,3	38	3,4

In table 5, with a duration of increasing the load of 10 kg for an asymmetrical load of 30 cm from a symmetrical position at 20 kg to 60 kg with a motor speed of 5 Hz, if calculated based on the average value, overall with the addition of a load of 10 kg there is an increase in slip of 26% from the lowest load of 20 kg.

Table 6. Asymmetric load position (30 mm offset) with Motor speed of frequency 8 Hz

No	m(kg)	Nmotor (rpm)	Npully (rpm) Theoretical	Npully (rpm) Actual	Slip (%)
1	20	211	70,3	68	3,3
2	30	211	70,3	68	3,3
3	40	209	69,7	67,5	3,1
4	50	208	69,3	67	3,4
5	60	209	69,7	67	3,8

In table 6, with a duration of increasing the load of 10 kg for asymmetric loading of 30 cm from a symmetrical position at 20 kg to 60 kg with a motor speed of 8 Hz, based on the average value, that overall with the addition of a load of 10 kg there is an increase of 28% from the lowest load of 20 kg.

The graphical relationship between load and slip percentage for the symmetric load position at motor frequencies of 5 Hz and 8 Hz is shown in Figure 4.

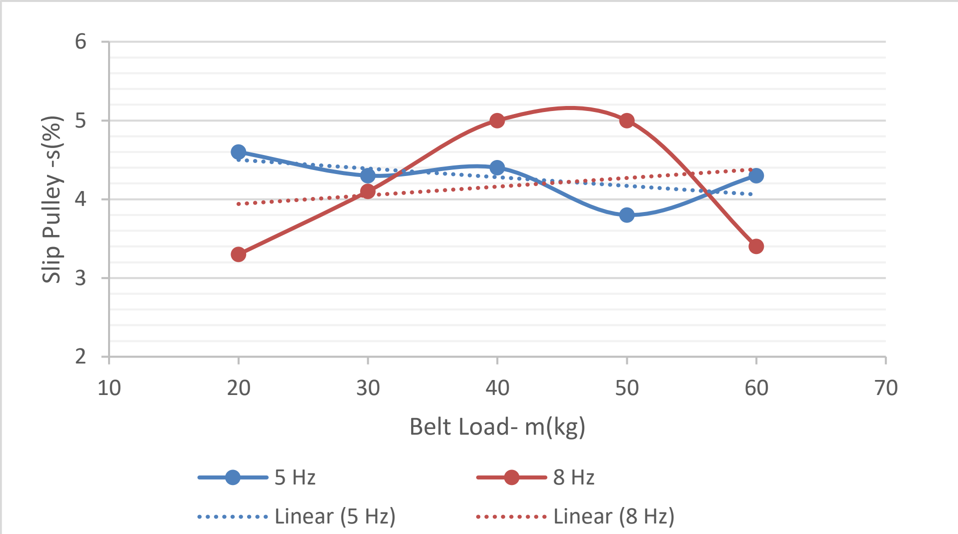

Figure 4. Load versus slip at motor frequencies of 5 Hz and 8 Hz (symmetric load)

The graphical results in Figure 4 with a symmetrical load show results that correspond to the pulley slip values in Table 3 and Table 4, where at a speed of 5 Hz there is a tendency for the slip value to decrease with the addition of belt load with a duration of 20 kg to 60 kg, increasing for a speed of 8 Hz and not having much effect. Meanwhile, the relationship between load and slip percentage for the asymmetric load position is illustrated in Figure 5.

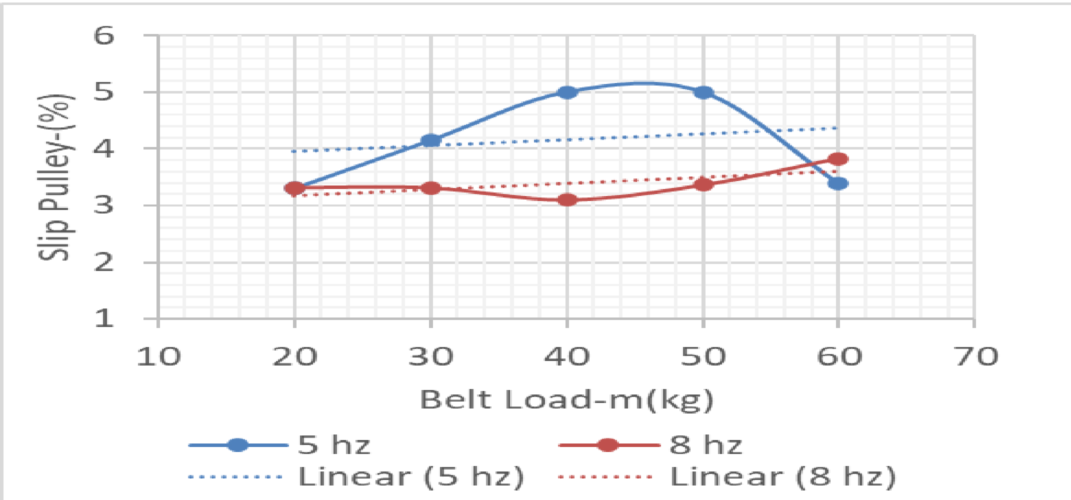

Figure 5. Load versus slip at motor frequencies of 5 Hz and 8 Hz (asymmetric load)

For asymmetric loading in Figure 5, it also corresponds to the pulley slip values in Table 5 and Table 6, where the tendency for increased slip is more visible, both with increasing load and at higher motor frequencies.

3.2 Discussion

After the process of making the conveyor belt system is completed, it is ensured that the dimensions and materials used are in accordance with the design drawings and the assembly results, this can be seen in figure 2a for the design drawing results and figure 2b for the assembly results of the conveyor belt system with system dimensions of 3m long, 30 cm wide and 70 cm high construction. Meanwhile, for the load testing used consists of pieces of iron with a size of ± (15 cm x 10 cm) with a load variation of 20 to 60 kg of weighing results, and the rotation speed of the drive pulley and the driven pulley is measured using a PLC-based monitoring system integrated with an inverter and HMI to control a three-phase induction motor. Measurements are carried out with an operating frequency of 5 Hz – 8 Hz on the inverter for symmetrical and asymmetrical load conditions, and for the output readings of the drive and driven pulleys are read in rpm units on the HMI (human machine interface) monitor.

For symmetrical and asymmetrical load configurations, experimental results at motor frequencies of 5 Hz and 8 Hz indicate that higher rotational speeds tend to produce lower slip percentages, as seen in Tables 3 and 4 for symmetrical loads and Tables 5 and 6 for asymmetrical loads. A trend toward increased slip changes can be observed in Figure 4 for symmetrical loads and Figure 5 for asymmetrical loads. [11], [12]

Based on the trend results seen in Figures 4 and 5, for symmetrical loads, the increase in slip changes is not significant and is heterogeneous with a loading duration of 10 kg from 20 kg to 60 kg. While for asymmetrical loads, the increase in slip is more obvious with the same load duration, as shown in Figure 5 [13].[14]. This behavior indicates that higher rotational speeds improve the stability of the belt-pulley contact and reduce slip even under uneven loading conditions [15].

Based on the two graphs, both symmetrical and asymmetrical load configurations show a tendency for slip to increase with increasing load magnitude. This phenomenon is attributed to the increase in tangential forces acting on the belt, which exceed the available frictional resistance between the belt and pulley as the load increases [16] [17].

However, when comparing average slip values at identical rotational speeds, the asymmetrical load condition consistently produces higher slip than the symmetrical condition. This effect is particularly pronounced at 5 Hz, where the average slip increases from 4.03% (symmetrical) to 4.20% (asymmetrical). The increase in slip under asymmetrical loads can be attributed to uneven belt tension distribution, variations in local contact pressure, and reduced effective friction at the pulley-belt interface [18] [19].

Overall, these results confirm that load symmetry and rotational speed are critical parameters influencing slip behavior in belt conveyor systems. Asymmetrical load conditions significantly exacerbate slip, especially at lower operating speeds, thereby reducing transmission efficiency and potentially accelerating component wear [20].

4. Conclusion

The experimental results show that for motor speeds of 5 Hz and 8 Hz, both on symmetrical and asymmetrical loads, at lower speeds on the motor of 5 Hz, the slip value is higher because the effectiveness of contact between the belt and the pulley is relatively small, and with the addition of a heavier load, the slip value also has an impact on increasing. When compared to symmetrical loads with asymmetrical loads, the increase in slip value is not so visible with the addition of loads from 20 kg to 60 kg, as in figure 4, while with asymmetrical loads, the addition of the same load gives a clearer effect on increasing slip value, as seen in figure 5

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