From Conventional Steel Ropes to High Performance Polymer Coated Traction Means: The Journey of Traction Elevator Systems

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KEY WORDS: Elevator Suspension Media, Coated Traction Products, Steel Ropes, Traction Elevator System, MATLAB Simulation

ABSTRACT:

The evolution of traction elevator systems has been remarkable, transitioning from a primitive machine room-based DC motor driven elevator systems to advanced Machine Room Less (MRL) Permanent Magnet Synchronous Motor (PMSM) driven elevator systems. Modern elevator systems are not only space and energy-efficient but also require less maintenance. This evolution owes much to the advancements in the suspension media technology. The introduction of coated traction products as the suspension media for low rise and mid-rise elevator systems resulted in smaller sheave-motor combination, paving the way for MRL elevators. However, the coated modern elevator systems with coated traction products bring forth additional implications in design, installation, and operation, requiring significant attention. This paper presents an overview of coated traction products and explores the design of elevator systems utilizing such suspension media. It delves into various performance metrics, including energy efficiency, ride comfort, lifespan, and sustainability, comparing them with conventional elevator systems. Where applicable, simulation results using MATLAB are provided to support the claims.

NOMENCLATURE

k_{car} - Spring constant of the rope on the car side (N/m) = *EA/L*

where E- Modulus of Elasticity of rope (N/m²), A-Area of Cross section of the rope (m²) and L-Length of the rope (m)

k_{cw} - Spring constant of the rope on the counterweight side (N/m)

r_r - Roping ratio

r_t - Radius of traction sheave (m)

n_r - Number of ropes

b_{car}- Damping coefficient of the rope on the car side (Ns/m)

b_{cw} - Damping coefficient of the rope on the counterweight side (Ns/m)

J_T - Inertia of Traction Machine (Net inertia including inertia of the motor and traction sheave) (kgm^2)

m_{car} - Mass of the elevator car including the empty cabin weight (kg)

m_{cw} - Mass of the elevator counterweight (kg)

ω_m – Angular velocity (mechanical) of the motor (rad/s)

v_{car} - Linear velocity of the car (m/s)

v_{cw} - Linear velocity of the counterweight (m/s)

v_m - Linear velocity of the motor (m/s)

a_{car} - Linear acceleration of the car (m/s^2)

a_{cw} - Linear acceleration of the counterweight (m/s^2)

g - Acceleration due to gravity (m/s^2)

T_{em}- Electromagnetic torque of the motor (Nm)

α_m- Angular acceleration of the traction sheave (rad/s^2)

P- Payload (kg)

Q- Empty cabin weight (kg)

BF- Balance Factor (in %)

N- Number of ropes

RW- Rope Weight (in Kg)

1. INTRODUCTION:

Traction elevator systems have been pivotal in the significant growth of multi-storey buildings and apartments over the past few decades. Their impact is so profound that the energy consumption of elevator systems is now one of the key factors in LEED (Leadership in Energy and Environmental Design) certification for sustainable building practices (TK Elevator, 2020). Elevators can account for up to 10% of the total energy consumption in high-rise buildings (TK Elevator, 2024).

The growing emphasis on sustainability is driving the development of newer elevator systems that are both energy and space efficient. For example, the gearless Permanent Magnet Synchronous Motor (PMSM) is the preferred motor technology in modern elevators due to its high efficiency compared to the geared induction motors of the past (Otis, 2015). To further enhance the energy efficiency of the elevator system, it is essential to investigate new types of suspension media. This is because the conventional steel ropes require a traction sheave with a diameter at least 40 times that of the rope, which limits the reduction in size and rating of the motor for a given passenger capacity. A promising solution to this issue is the adoption of polymer coated suspension media, which is gaining popularity in low rise and mid-rise elevators in Europe and America (Elevator World, 2019). The polymer coated suspension media are also known as “Coated Traction Product (CTP)” in market parlance. Given the rapid growth of the Indian elevator market, particularly in the low-rise and mid-rise segments, it is essential to consider coated traction products to optimize these new systems.

Besides the benefit of using a smaller sheave with the coated traction product, it also offers numerous other advantages, including higher traction capability, longer lifespan, reduced noise, and lubrication-free operation. Each of these advantages has subtle implications in the design and operation of the elevator system. For example, the higher traction capability compared to conventional ropes enables the use of a lighter cabin and counterweight for the same payload (Elevator World, 2023). The longer lifespan contributes to sustainability and results in less downtime. The reduced noise enhances ride comfort, and the lubrication-free operation keeps the hoist-way clean and reduces maintenance requirements. However, the installation of coated traction products is crucial for fully leveraging their benefits. These products are highly sensitive to factors such as fleet angle, twist, and groove pressure (Brugg Lifting, 2025).

This paper aims to explore the various above aspects in detail and provide a comprehensive understanding of such elevator systems. The rest of the paper is structured as follows: Section 2 delves into the construction of coated traction products. Section 3 analyses an elevator system using coated traction products as the suspension medium, discussing the benefits and implications of such a system. Section 4 presents simulation results using MATLAB, validating some of the key advantages of these elevator systems. The specifications of BRUGG Lifting’s proprietary coated traction products are used for validation. Finally, Section 5 concludes the paper and outlines potential prospects.

2. COATED TRACTION PRODUCT:

The Coated Traction Product (CTP), as the name implies, are the traction or suspension media where steel cables or cords are enclosed in a polymer jacket, as shown in Fig. 1. The CTP is of two types namely the “Coated Traction Product-Rope” and “Coated Traction Product-Belt”. When steel cables are enclosed inside a polymer jacket, they are referred to as “Coated Traction Product-Rope” (Fig. 1 (a)). Similarly, when multiple steel cords in parallel are enclosed inside a polymer jacket, they are known as “Coated Traction Product-Belt” (Fig. 1 (b)) or “Coated Steel Belt”. The polymer employed is “Thermoplastic Poly Urethrane”, popularly known as “TPU”. The wires used for the cord/ cable are special high tensile wires.

(a) (b)

Fig. 1 (a) Coated Traction Rope (b) Coated Traction Belt

Unlike the conventional steel ropes, the polymer in coated traction products interacts with the traction sheave surface. Therefore, it is not a "steel-steel" interaction but rather a "polymer-steel" interaction. This distinction is critical for coated traction products. The "polymer-steel" interaction offers numerous advantages, as explained in the introduction section, provided the geometry of the sheave surface and its properties are optimized according to the specifications of the polymer coating. The polymer coating increases the Coefficient of Friction (COF) between the rope/ belt and sheave. This increases the available frictional force between the rope/ belt and sheave resulting in higher traction.

3. ANALYSIS OF ELEVATOR SYSTEM WITH COATED TRACTION PRODUCT:

3.1 Modelling of Elevator System:

A typical traction elevator system with 2:1 roping configuration is shown in Fig. 2.

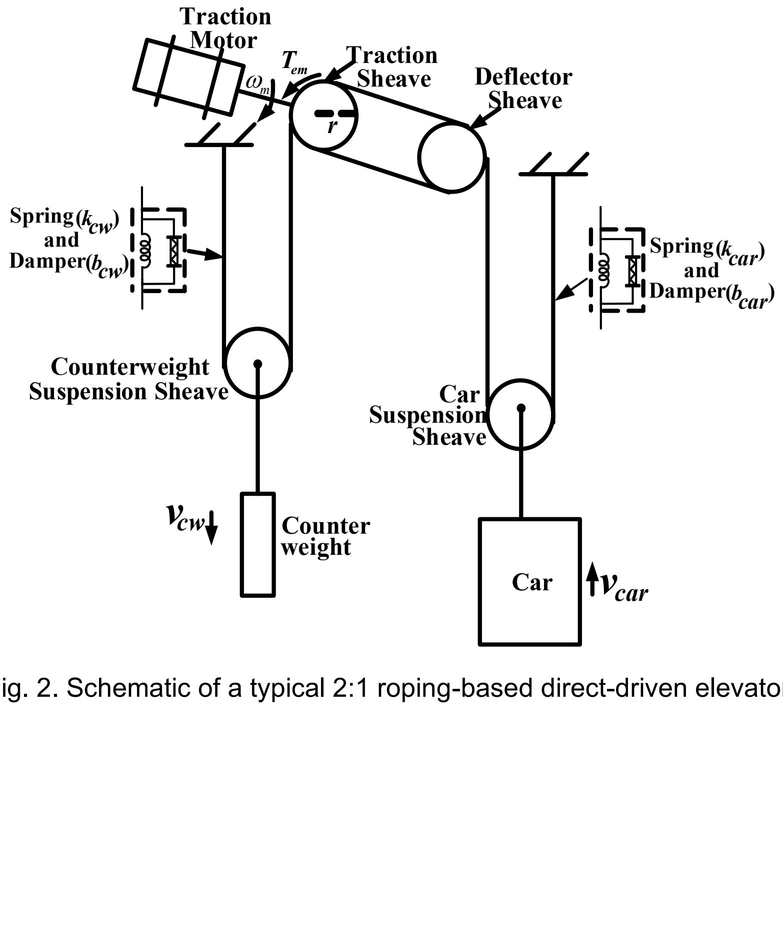


Fig. 2. Schematic of a typical 2:1 roping-based direct-driven elevator

The key modelling are the dynamic equations of the traction sheave, elevator car and the counterweight (S.Rangarajan,2024) as shown below:

$$J_T \alpha_m = T_{em} + \frac{r_t n_r}{r_r}\left[k_{cw}\int(v_m - r_r v_{cw})dt + b_{cw}\frac{d\int(v_m - r_r v_{cw})dt}{dt} - k_{car}\int(v_m - r_r v_{car})dt - b_{car}\frac{d\int(v_m - r_r v_{car})dt}{dt}\right] \quad (2.1)$$

$$m_{car} a_{car} = \left[k_{car}\int(v_m - r_r v_{car})dt + b_{car}\frac{d\int(v_m - r_r v_{car})dt}{dt}\right] - m_{car} g \quad (2.2)$$

$$m_{cw} a_{cw} = m_{cw} g - \left[k_{cw}\int(v_m - r_r v_{cw})dt + b_{cw}\frac{d\int(v_m - r_r v_{cw})dt}{dt}\right] \quad (2.3)$$

From (2.1) to (2.3), it is evident that at steady state when the elevator is travelling at its rated speed or constant velocity, the electromagnetic torque of the motor is,

$$T_{em} = \frac{r_t}{r_r}(m_{cw} - m_{car})g \quad (2.4)$$

In the above analysis, mass of the suspension media is neglected as it is negligible compared to the mass of the car in low rise and mid-rise elevator system.

3.2 Advantages of Coated Traction Products:

3.2.1 Reduction in Motor Rating:

(2.4) demonstrates that the only way to reduce the torque rating of the motor for a given passenger capacity, roping ratio, and balance weight is to decrease the radius of the traction sheave. However, reducing the radius of the traction sheave increases the bending fatigue of the suspension media, making it impossible to reduce the radius beyond allowable limits. According to standards, the diameter of the traction sheave for conventional steel ropes should be at least 40 times the diameter of the rope. This limitation affects the sizing of the traction motor.

For Coated Traction Product-Rope, the standards allow the diameter of the traction sheave to be as low as 25 times the diameter of the enclosed steel cable (excluding the coating thickness). Similarly, for Coated Traction Product-Belt, the diameter must be 40 times the diameter of the steel cord, but the cord diameter itself is quite small. For instance, the 8.1 mm diameter Coated Traction Product-Rope manufactured by BRUGG Lifting has a steel cable diameter of 6.2 mm, allowing the traction sheave diameter to be theoretically 155 mm. It is common to use a 160 mm traction sheave for an 8.1 mm diameter Coated Traction Product-Rope. The protective polymer coating and high tensile wires allow the reduction in the sheave diameter without compromising the lifetime. Likewise, for the 53 kN Coated Traction Product-Belt manufactured by BRUGG Lifting, the steel cord diameter is 2.1 mm, allowing the traction sheave diameter to be theoretically as low as 84 mm. BRUGG Lifting recommends 100 mm diameter sheave in this case to achieve better lifetime. It is worthwhile to compare this with the 8 mm diameter conventional steel rope that requires a traction sheave of 320 mm diameter. Hence, Coated Traction Product-Rope results in 50% reduction in traction sheave diameter while Coated Traction Product-Belt results in 68.75% reduction in traction sheave diameter. A diagrammatic representation of reduction in sheave diameter with the conventional and Coated Traction Product-Rope is shown in Fig. 3.

Reducing the torque rating of the motor decreases the motor currents. Consequently, the rating of the switches in the frequency converter (inverter) will also decrease, leading to enhanced thermal performance of both the motor and the converter. The overall cost of the motor and converter will also decrease leading to upfront cost savings.

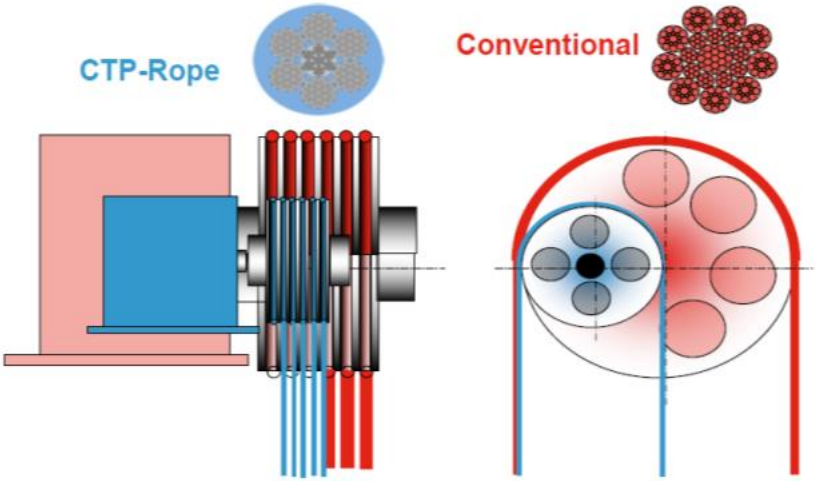


Fig. 3. Schematic representation of sheave diameter with the conventional rope and Coated Traction Product (CTP) Rope (CTP-Rope)

3.2.2 Higher Traction Capability:

The polymer coating's interaction with the steel surface of the traction sheave results in a Coefficient of Friction (COF) which is approximately three times higher than that of conventional steel ropes. Due to this high inherent COF, aggressive groove geometries such as V grooves or undercut U grooves are unnecessary. Additionally, double warping is not required, which reduces space requirements, the number of ropes, and installation complexity. Another advantage of higher traction is the potential to reduce the cabin weight and counterweight for a given payload. For example, consider the following system parameters:

P=400 kg, Q=750 kg, BF=50%, RW=0.25, r_r=R=2, H=25 m, SF=12, N=3, the traction calculation with the 125% loading at the bottom position is as follows:

$$T_1 := (1.25 \cdot P + Q)\,\frac{(g+a)}{R} + (WHR \cdot (g + R \cdot a)) - \frac{F_{rcar}}{R} = 6313.031\ N \quad (2.5)$$

$$T_2 := (CW)\,\frac{(g-a)}{R} + \frac{F_{rcw}}{R} = 4658.159\ N \quad (2.6)$$

$$\frac{T_1}{T_2} = 1.355 \quad (2.7)$$

With CTP whose COF is around 0.25,

$$e^{f \cdot \alpha} = 2.193 \quad (2.8)$$

With the conventional rope whose COF is around 0.09 with the U-groove sheave,

$$e^{f_{sr} \cdot \alpha} = 1.327 \tag{2.9}$$

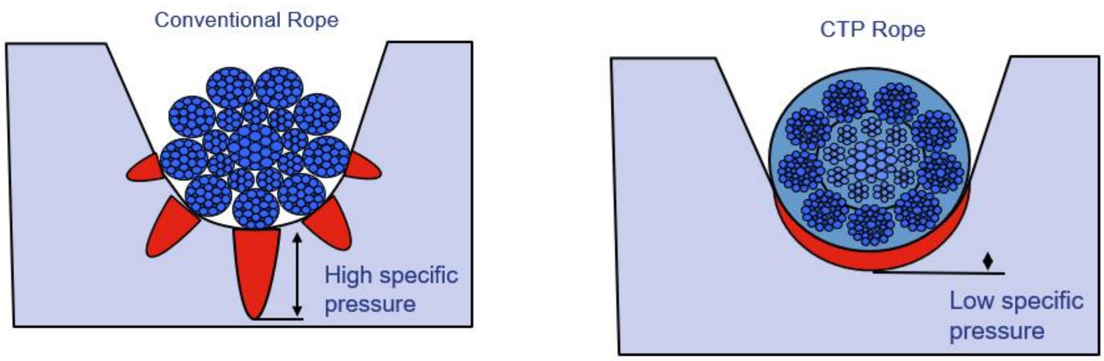
We can see very clearly that CTP satisfies the traction condition ((2.7) < (2.8)) whereas the conventional rope with U groove does not ((2.7) > (2.9)). To satisfy the traction condition with the conventional rope, it is necessary to increase the cabin weight.

3.2.3 Reduction in Noise and Vibration:

Conventional ropes suffer from noise issues due to the steel-to-steel contact between the rope and the sheave. However, with coated traction products, the interaction is between polymer and steel, which significantly reduces noise. Additionally, the polymer coating is expected to dampen unintended vibrations during travel, for example due to resonance. As a result, ride comfort is greatly improved with coated traction products.

3.2.4 Increase in Lifetime:

The conventional rope experiences significant groove pressure (Fig. 4 (a)) due to the aggressive V groove or undercut U-groove design, which is intended to increase traction. This high pressure reduces the rope's lifespan. In contrast, coated traction ropes or belts allow for the use of a U groove, which results in lower groove pressure (Fig. 4 (b)). This lower pressure enhances the longevity of the suspension media, eliminating the need for rope replacement throughout the elevator's service life and thereby reducing associated maintenance costs and downtime.



(a) *(b)*

Fig. 4 Schematic representation of groove pressure with (a) Conventional rope (b) CTP rope

3.2.5 Space Efficiency:

Coated traction products allow for a larger cabin size within the same hoistway dimensions (see Fig. 5). Consequently, the number of elevators required in a building decrease, as each elevator can now accommodate more passengers. For instance, while an elevator with a conventional rope can hold approximately 9 passengers, a CTP-rope based elevator can hold around 12 passengers in the same hoistway. Therefore, a building that would typically require 4 elevators with conventional ropes would only need 3 elevators with CTP. This not only eliminates the cost of one complete elevator system but also results in additional space and reduction in building energy consumption.

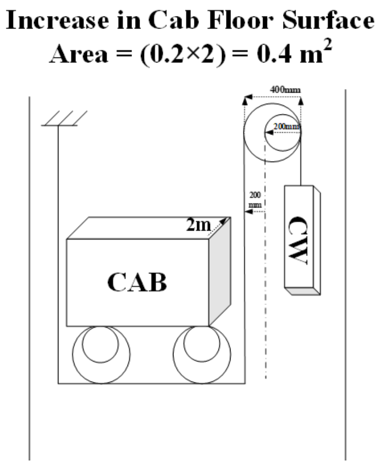


Fig. 5 Schematic representation of reduction in cab size due to CTP-rope. The comparison is between 10 mm conventional rope and 10 mm CTP-rope.

3.2.6 Lubrication-Free Operation:

Coated traction products eliminate the need for periodic lubrication, which not only reduces maintenance but also keeps the hoist-way clean. In contrast, conventional ropes require regular lubrication to ensure smooth operation and maintain their service life.

3.2.6 Sustainability:

Consider the model lift shown below:

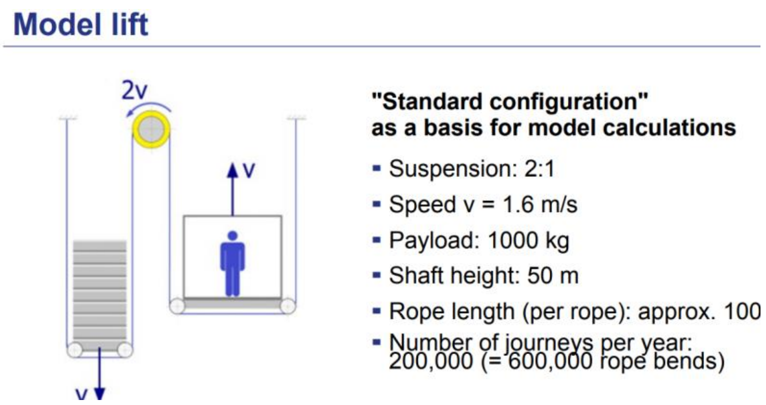


Fig. 6 Model lift for CO_2 calculation.

The CO_2 emission per year due to the rope material usage for the various types of suspension media including the conventional steel core rope (SCX9), CTP-Rope and CTP-Belt is shown in Fig. 7. The carbon footprint is significantly reduced with CTP resulting in sustainability and helps in green building operation. The dark blue and light blue in the graph indicate CO_2 emission due to steel material usage and TPU usage respectively.

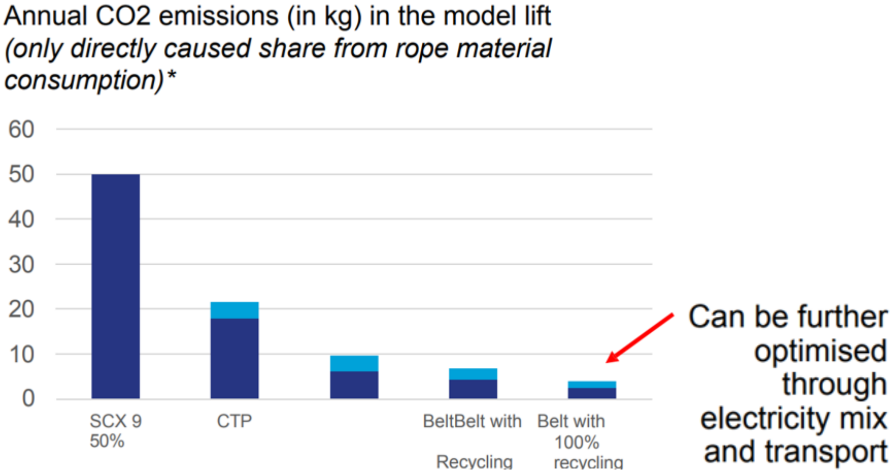


Fig. 7 Bar chart depicting the CO_2 emission (in kg) for various types of suspension media considering the model lift shown in Fig. 6

3.3 Installation Requirements of Coated Traction Products:

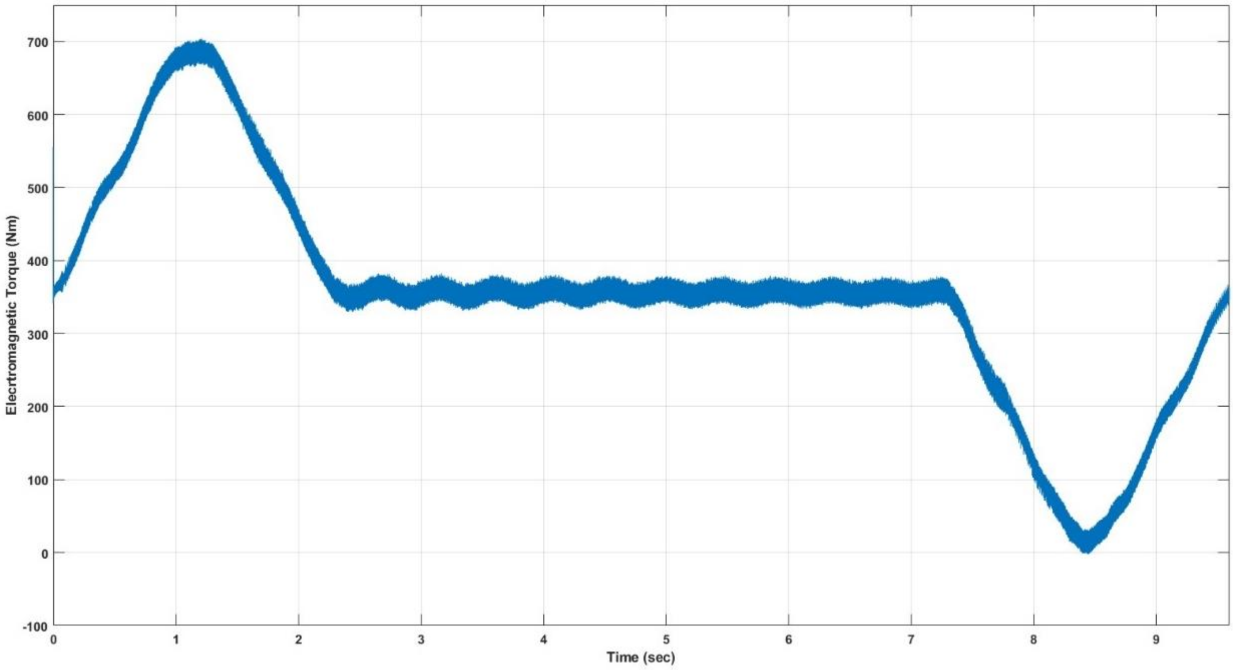
Unlike conventional ropes, CTP require high-quality installation. Some of the critical points to follow when installing CTP ropes or belts are:

1. **Inspect Traction and Deflector Sheaves**: Ensure that the geometry and properties of the sheaves meet the specifications provided by the CTP manufacturer.
2. **Avoid Contaminants**: CTPs are sensitive to lubricants, fats, oils, and similar substances. Ensure that all materials in contact with the CTP are free of these contaminants.
3. **Minimize Fleet Angle**: Keep the fleet angle as small as possible during installation, ideally within ± 0.5°.
4. **Prevent Twisting**: Ensure that the rope remains untwisted both before and during installation.
5. **Avoid Reverse Bending**: Do not allow any reverse bending of the rope.

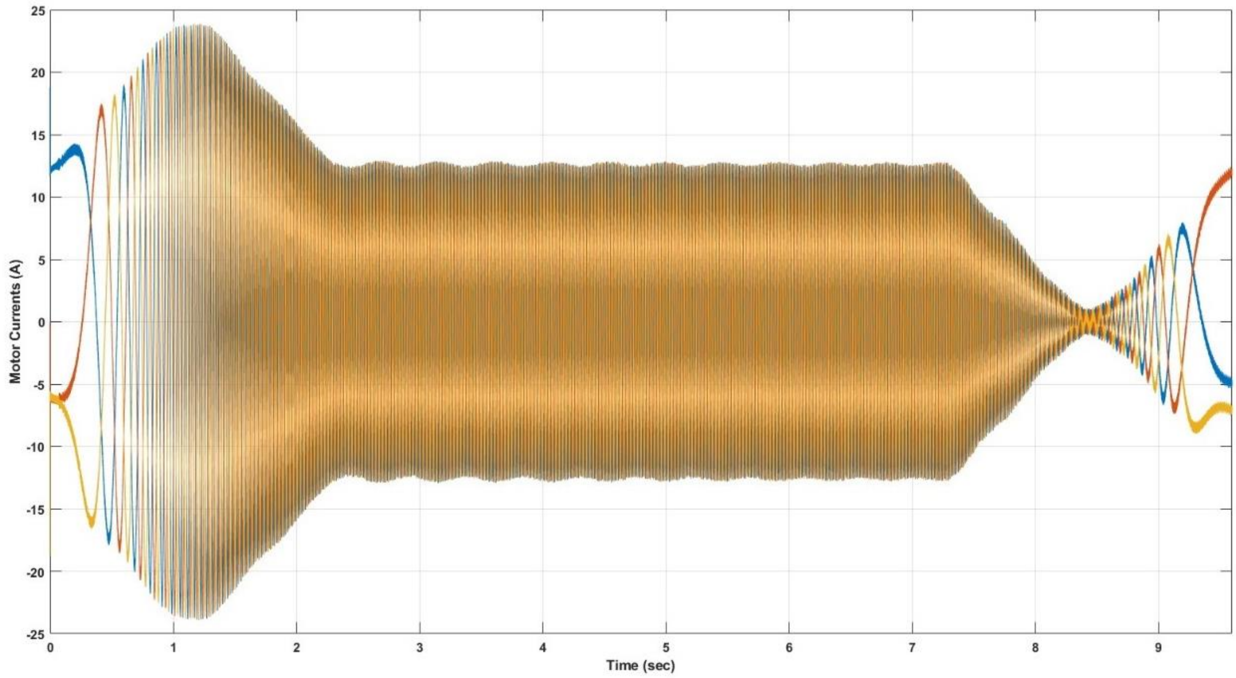
4. SIMULATION RESULTS:

The system depicted in Fig. 2 has been modelled in MATLAB-Simulink to simulate and compare the performance of an elevator system using conventional rope, CTP-Rope, and CTP-Belt. The elevator system parameters are P=907 kg, Q=1360 kg, SF=12, and BF=50%. The conventional rope is an 8 mm diameter Natural Fiber Core (NFC) rope manufactured by BRUGG Lifting. The CTP-Rope is an 8.1 mm diameter rope, and the CTP-Belt is a 53 kN belt, both produced by BRUGG Lifting. Figs. 8-10 illustrates the simulation results with the conventional rope, CTP-Rope, and CTP-Belt respectively. Based on Figs. 8-10, Table I presents the performance comparison of the three types of suspension media. The results show a significant reduction in the torque rating, current rating, and energy consumption with the CTP products compared to the conventional rope. Among the CTP-Rope and CTP-Belt, the CTP-Belt excels in terms of torque rating and current rating. However, both CTP products offer superior performance compared to the conventional rope.

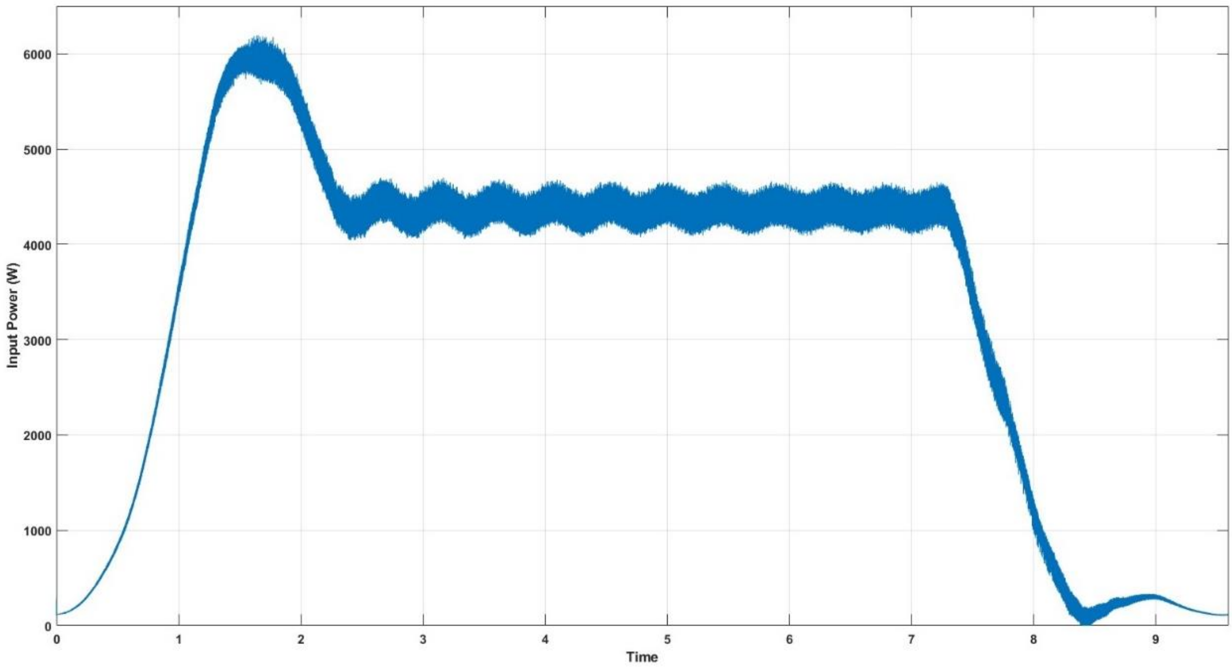
CONVENTIONAL ROPE RESULTS:



(a)



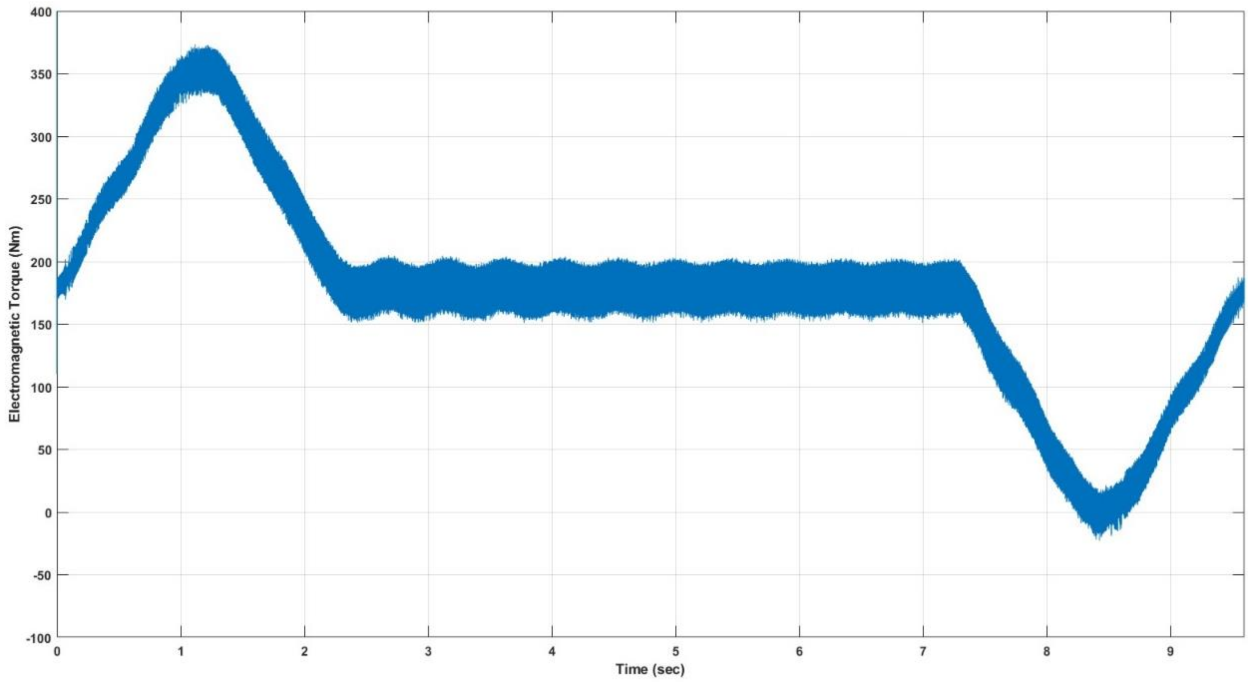
(b)



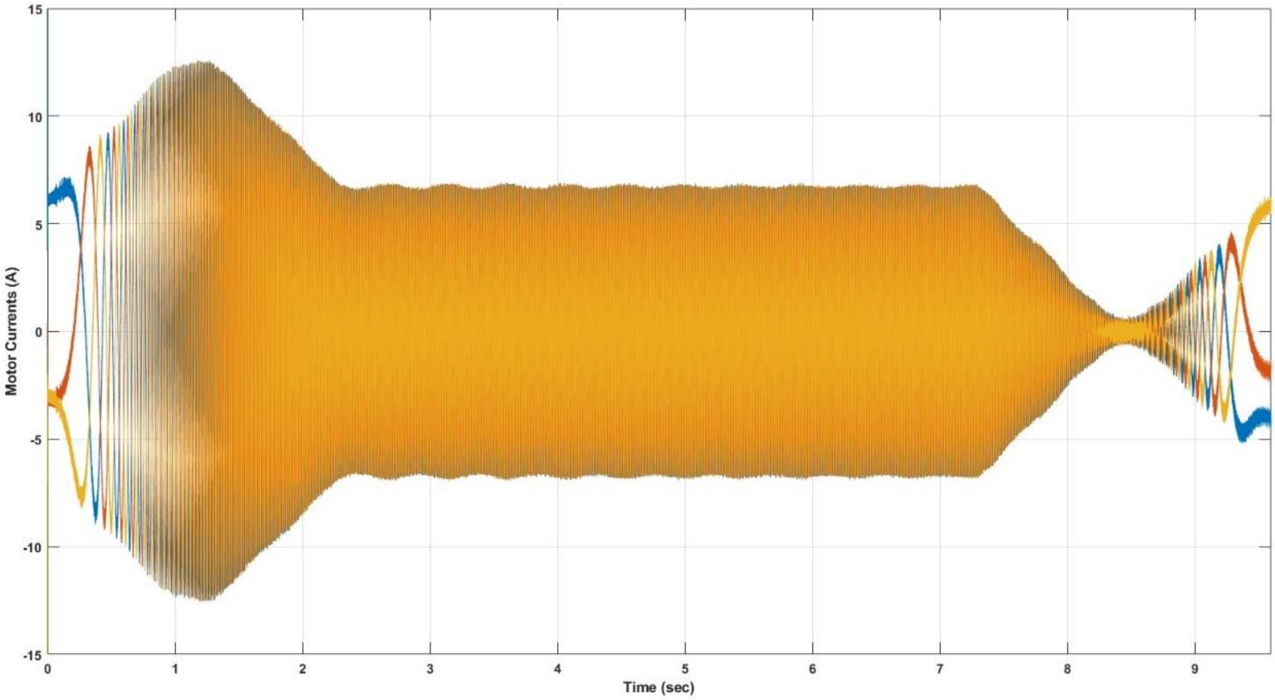
(c)

Fig. 8 (a) Electromagnetic torque of the motor with conventional rope (b) Three phase currents of the motor with conventional rope and (c) Input power of the system with conventional rope

CTP-ROPE RESULTS:



(a)



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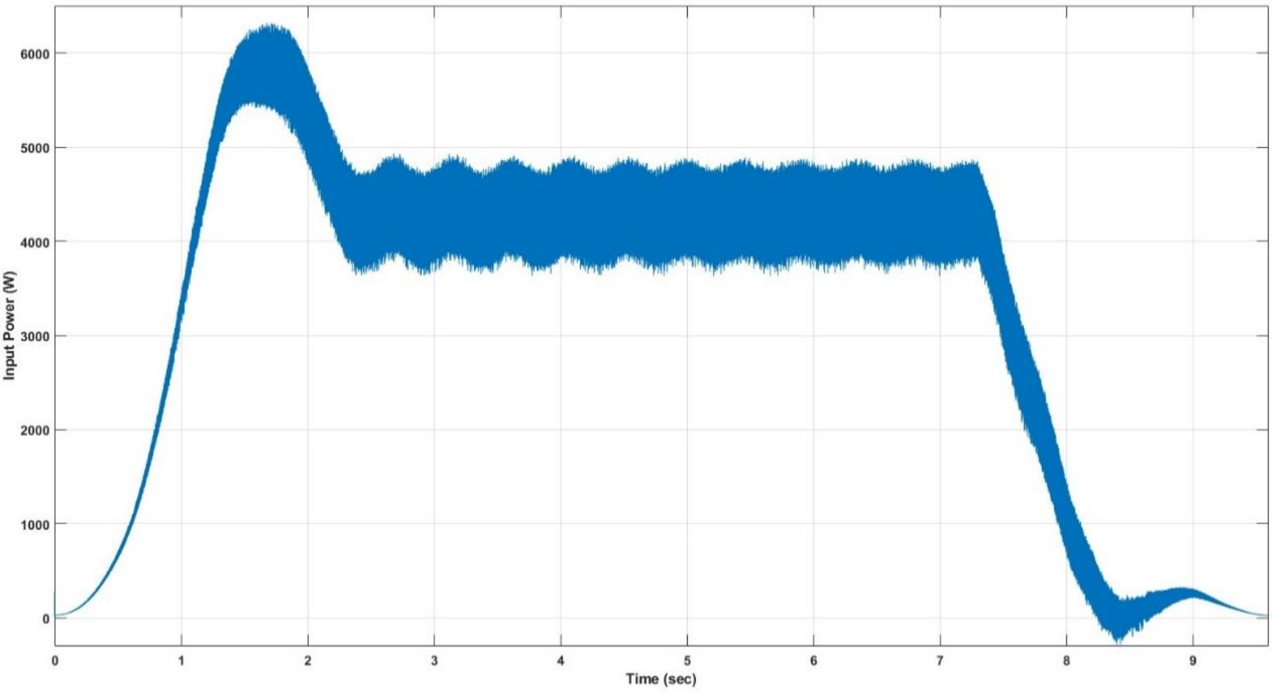
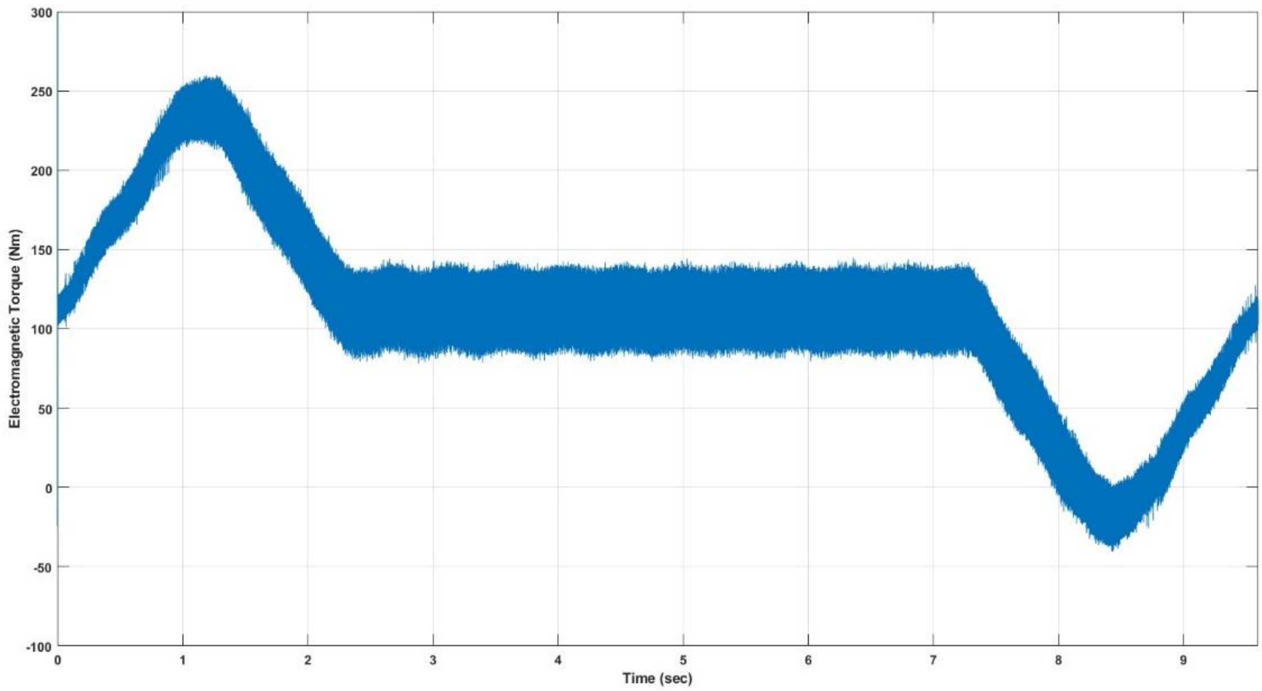


(c)

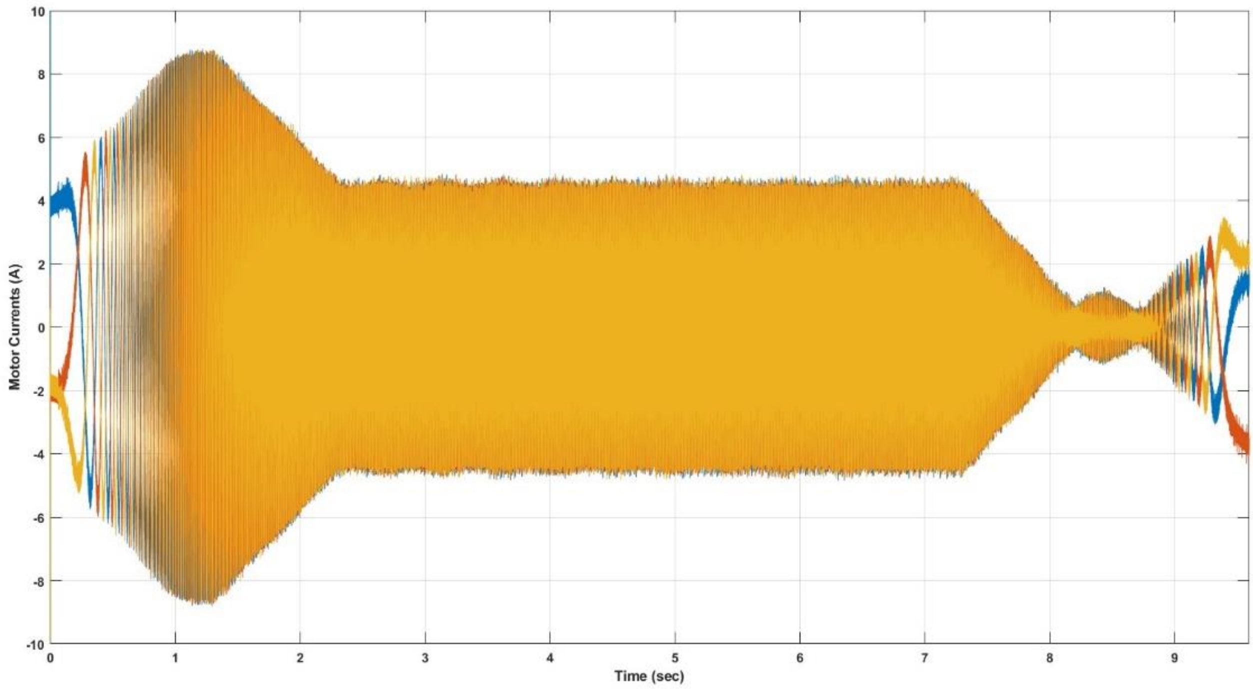
Fig. 9 (a) Electromagnetic torque of the motor with CTP-Rope (b) Three phase currents of the motor with CTP-Rope and (c) Input power of the system with CTP-Rope

In these simulations, the dynamic performance of the CTP products has not been considered (S.Rangarajan,2024), as it falls outside the scope of this work. Hence, the oscillations in the waveforms may not completely reflect the dynamics of the CTP system.

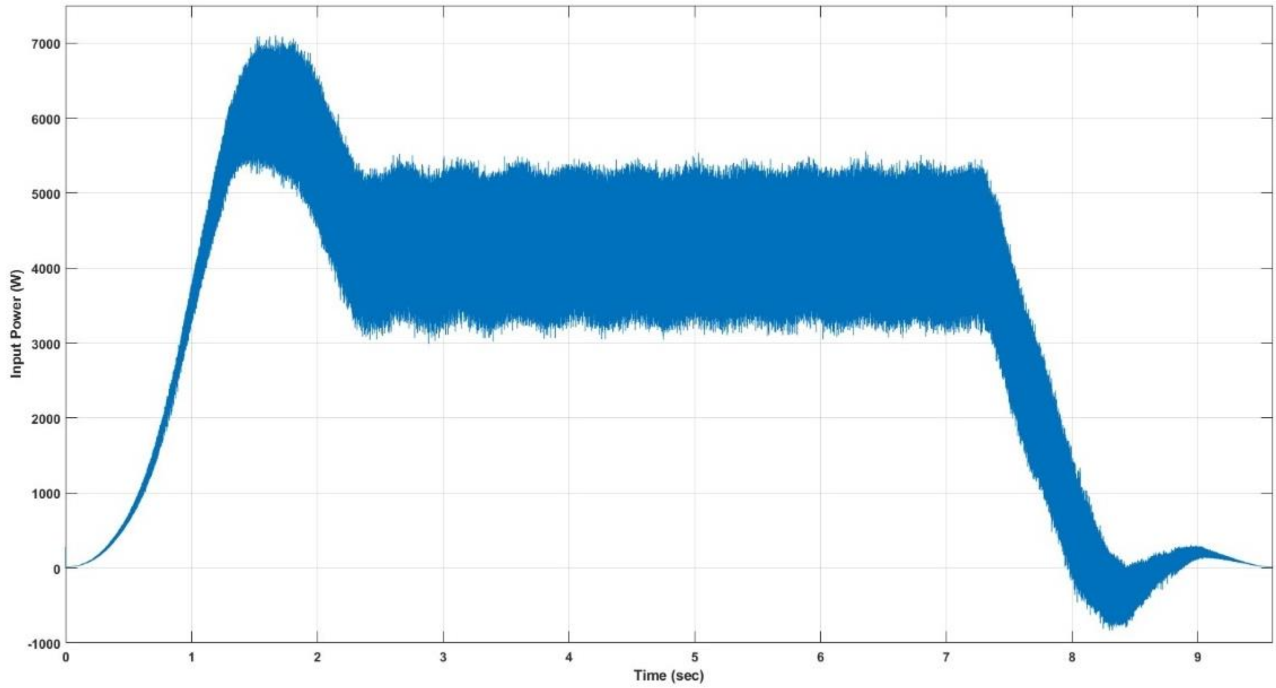
CTP-BELT RESULTS:



(a)



(b)



(c)

Fig. 10 (a) Electromagnetic torque of the motor with CTP-Belt (b) Three phase currents of the motor with CTP-Belt and (c) Input power of the system with CTP-Belt

Table I. Comparison of Conventional rope, CTP-Rope and CTP-Belt based on simulation

Parameter	**Conventional Rope**	**CTP-Rope**	**CTP-Belt**
Motor Torque (peak)	~ 700 Nm	~ 370 Nm	~ 250 Nm
Motor Current (peak)	~ 24 A	~ 12.5 A	~ 8.5 A
Number of elevators for handling 48 passengers in a building	4 (13 passengers per elevator)	3 (16 passengers per elevator)	3 (17 passengers per elevator)
Energy Consumption per travel for the simulated trajectory	129.34 kJ	94.107 kJ	93.54 kJ
Annual energy consumption considering 30,000 trips at full load for the simulated travel	3.88 GJ	2.82 GJ (27.3% savings)	2.80 GJ (27.8% savings)

5. CONCLUSION:

Most of government regulations and industry standards are increasingly emphasizing clean energy and sustainability. As one of the major energy consumers in a building, traction elevators are expected to comply with these standards and contribute to green building initiatives. Additionally, the global dependence on rare earth elements for traction motors is becoming a significant concern. Therefore, it is essential to optimize the design, operation, and maintenance of traction elevator systems. This paper discusses in detail how using coated traction products as suspension media in traction elevators can help achieve these objectives. As a global manufacturer of CTP and a supplier to OEMs worldwide, BRUGG Lifting is well-positioned to introduce this technology to the Indian elevator market and support the OEMs. Future technology could explore the potential of developing a suspension media compatible with new types of motors, such as Switched Reluctance Motors (SRM). This innovation could eliminate the dependence on rare earth elements.

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7. BIOGRAPHICAL DETAILS

Sriram Rangarajan is currently a Project and Application Engineer at BRUGG Lifting. He earned his Ph.D. from the Indian Institute of Technology Bombay, Mumbai, India. His thesis focused on "Investigations of Control Schemes to Improve the Performance of PMSM Driven Elevator Systems."

Anand Ganji is the Head of System Engineering at BRUGG Lifting. He holds a degree in Mechanical Engineering and a Postgraduate Diploma in Technology and Engineering Management. With over 18 years of global experience in product development and systems engineering, he is a member of the International Association of Elevator Engineers (IAEE). Anand currently heads the System Engineering function and leads business development efforts in India.

Michael Seigfried has been serving as the Chief Technological Officer (CTO) at BRUGG Lifting for the past 8 years. He holds a Master of Science degree in Materials Science from ETH Zurich, Switzerland, and has held various positions within the BRUGG group before becoming CTO.