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THE EFFECT OF TOTAL HARMONIC DISTORTION LEVEL ON EFFICIENCY IN TURBO BLOWER

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Abstract: *This study presents a comparative analysis investigating the impact of Total Harmonic Distortion (THD) levels on the efficiency of two magnetic bearing HAUS Turbo Blower models. Both models operate under identical conditions and load settings, with the only difference being the presence of a harmonic reduction filter in one of them. The analysis involves examining power quality, energy consumption, and harmonic distortion values using an energy analyzer. Experimental data is collected from various points on the turbo blowers and supplemented by weather station measurements. The focus is on energy consumption, harmonic values, and component temperatures, particularly the motor and Variable Frequency Drive (VFD). Efficiency parameters like Polytropic efficiency and specific power consumption are analyzed, providing insights into the relationship between THD levels and component efficiency. This research aims to optimize the design and operational parameters of magnetic bearing turbo blower systems.*
Key words: *THD, Energy Efficiency, Turbo Blower, Packet Power, Volume Flow, Pressure Rise*

1. INTRODUCTION

The efficient management of harmonic generation in power systems is crucial for ensuring the economic viability, environmental sustainability, and reliability of electricity supply. This significance becomes even more pronounced as modern power systems grow increasingly complex and integrated, underscoring the need for a holistic approach to guarantee a stable and sustainable electricity supply. Efficiency is crucial in industry to cut costs and minimize losses. Managing harmonic generation is key, especially through the widespread use of variable speed induction motors. If not addressed carefully, induced losses from harmonics can become significant. Implementing measures like harmonic filters and advanced motor control systems is essential for reducing losses and optimizing efficiency, contributing to both cost savings and environmental sustainability [1]. The evolution of power systems is steering towards an augmented utilization of renewable energy sources and an increased prevalence of power electronic devices. This transition, while promising sustainability, introduces challenges in power quality, particularly concerning harmonics and their diverse sources. The analysis emphasizes the complexity of understanding and controlling harmonics, involving intricate tasks such as modeling, tracing, and implementing measures to mitigate their impact [2].

Highlighting the critical role of electricity in modern society, the paper explores the globalization of the electricity market and the interconnection of regional power grids, underscoring the need for ensuring the safe and stable operation of power grids. Power quality issues, including harmonic pollution and voltage sag [3], [4], pose threats to transmission and distribution networks, with estimated annual losses of approximately $26 billion in the United States alone, according to the U.S. Electric Power Research Institute (EPRI) [5].

Harmonics, present in power systems since the inception of AC systems, have recently collected increased attention due to two converging trends. Firstly, electric utilities are increasingly focused on improving power factor to avoid penalties. Secondly, the widespread

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adoption of power electronic equipment in modern industry aims at enhancing system dependability and efficiency. The manipulation of diverse harmonic frequencies with varying amplitudes allows the creation of distorted periodic waves of any desired shape [6]. Distorted periodic waves can be analyzed using Fourier analysis, which decomposes them into a fundamental frequency and harmonic waves. This method is crucial for studying the impact of non-linear elements in power systems. Non-characteristic harmonics, known as 'inter-harmonics,' differ from integer multiples of the fundamental frequency, with cycloconverters being a notable source. Moreover, 'sub-harmonics' are frequencies lower than the fundamental frequency within the range of inter-harmonics [1].

Harmonics and interharmonics, present across low and high frequencies, result in adverse effects such as flicker, equipment overheating, increased network losses, interference in communication systems, and errors in control systems and digital meters [7], [8]. Additionally, interharmonics can disrupt the periodicity of the waveform, causing challenges related to desynchronization in measurement procedures based on the Discrete Fourier Transform (DFT) [9], [10].

The electricity supply sector currently faces a significant challenge of poor power quality. Voltage and energy issues, such as transient impulses, dips, swells, interruptions, and harmonics, have a notable impact on supply quality. This leads to intermittent or permanent failures in computers, communication interference, shortened equipment lifespan, motor damage, undesired switch tripping, and overloading of conductors and transformers, among other critical challenges. Addressing these issues is imperative for ensuring a reliable and efficient electrical infrastructure [11].

As the industrial landscape advances, the integration of power electronic devices, non-linear equipment, and shock loads emerges as primary sources of harmonic pollution. This poses a serious threat to electrical equipment requiring high precision, automation, and stable power supply, leading to increased losses for power users and hampering the efficiency of enterprise production. The paper underscores the urgent need for a comprehensive analysis and study of harmonic pollution in modern power systems to address these challenges and promote sustainable growth. Addressing harmonic pollution is crucial for ensuring the reliability and longevity of electrical infrastructure in the face of evolving industrial demands.

The increasing prevalence of power electronic systems and nonlinear loads is a major factor driving up harmonic distortion, negatively affecting the overall quality of electrical systems. As a result, there is a pressing need for power distribution companies to prioritize the precise reporting of electrical product quality to address these issues efficiently [10], [12–14].
The distortion rates in different scenarios exhibit distinct characteristics. In cases involving only harmonics, there is a notable prevalence of high harmonic distortion, indicating a significant deviation from the ideal sinusoidal waveform. This is accompanied by moderate levels of energy consumption distortion, suggesting a discernible impact on the efficiency of power utilization, and moderate manufacturing process distortion, reflecting potential disruptions in industrial operations. Conversely, when dealing with only interharmonics, particularly those assessed through the Discrete Fourier Transform (DFT), there is a combination of moderate interharmonic distortion, indicative of non-integer frequency multiples, along with high energy consumption distortion and moderate manufacturing process distortion. In scenarios where both harmonics and interharmonics coexist, there is an intensified presence of both high harmonic and interharmonic distortion, signifying a compounded effect on the power quality. This is further associated with elevated energy consumption distortion and manufacturing process distortion. Additionally, the incorporation of DFT-based analysis introduces a high level of desynchronization distortion, indicating potential challenges in maintaining synchronized processes. Table 1 provides a comprehensive overview of the diverse effects associated with harmonic and interharmonic distortions in various electrical scenarios [10].

Table 1

Distortion Characteristics, Manufacturing Parameters, and Energy Saving Parameters in Different Scenarios

Scenarios	Distortion Characteristics	Manufacturing Parameters	Energy Saving Parameters
Only Harmonics	High Harmonic Distortion	• Impact on precision manufacturing processes • Increased wear on machinery • Reduced efficiency in production • Potential damage to sensitive equipment	• Reduced energy efficiency due to harmonic losses • Higher energy consumption for cooling systems • Inefficient use of electrical equipment • Inaccuracies in energy monitoring systems
Only Interharmonics (DFT-based)	Moderate Interharmonic Distortion	• Desynchronization in automated processes • Potential inaccuracies in production data • Challenges in implementing energy-efficient technologies	• Fluctuations in energy consumption patterns • Challenges in implementing load optimization • Limited success in achieving energy performance goals
Harmonics and Interharmonics (DFT-based)	High Harmonic and Interharmonic Distortion	• Cumulative impact on precision processes • Increased complexity in maintenance • Inefficient use of energy recovery systems • Impact on synchronized manufacturing lines • Potential data inaccuracies • Resistance to the adoption of energy-efficient technologies	• Overall reduction in energy efficiency • Suboptimal utilization of energy-saving technologies • Difficulty in implementing effective power factor correction Increased energy losses in distribution systems

2. MATERIAL AND METHOD

In the course of our investigation, experiments were conducted with a magnetic bearing turbo blower machine, notable for its permanent magnet synchronous motor and hybrid cooling system. The machine was configured into two distinct series: the standard model E series and the I series, with the latter incorporating specialized components, namely an Active Front End (AFE) unit and an LCL filter, designed to achieve lower harmonic levels. The experimental protocol was rigorously adhered to ISO 5167 standards, with a focus on specific rotational speeds corresponding to predefined pressure rise values. Data acquisition was executed through a network of strategically positioned sensors on the machine, an advanced energy analyzer, and a test line purpose-designed to conform to ISO 5167 standards. The Nexus 1500+ energy analyzer, produced in compliance with IEC 61000-4-30 and EN 50160 standards, played a crucial role in enabling a thorough and accurate analysis of power quality, harmonics, and voltage characteristics within the electrical system. By ensuring stringent compliance with international standards, comprehensive insights were provided by the Nexus 1500+, delivering actionable information essential for the fine-tuning and optimization of the overall performance of the electrical system through targeted and strategic enhancements.

3. RESULTS AND DISCUSSION

The assessment of energy efficiency encompasses various key parameters, including flow rate, package power, pressure values, and flow rate per kW, for both E and I model machines. The quantification of energy efficiency achieved on an annual basis is summarized in the following table. By thoroughly studying and comparing these metrics, we gain valuable insights into the overall performance and sustainability of E and I model machines. This comprehensive analysis serves as a crucial reference for decision-makers, engineers, and stakeholders seeking to optimize energy consumption, enhance system efficiency, and make informed choices in the selection and operation of these machines in diverse industrial applications.

At 15000, 17000, 18000, 19000, 20000, and 21000 rpm values, polynomial equations were derived from the graphs for both E and I models. These equations involve substituting a constant flow rate value for the pressure rise variable, resulting in two separate equations. The obtained results were then proportioned to each other. The equations used for 15000, 17000, 18000, 19000, 20000, and 21000 rpm, along with the comparison results, are presented in the graphs below:

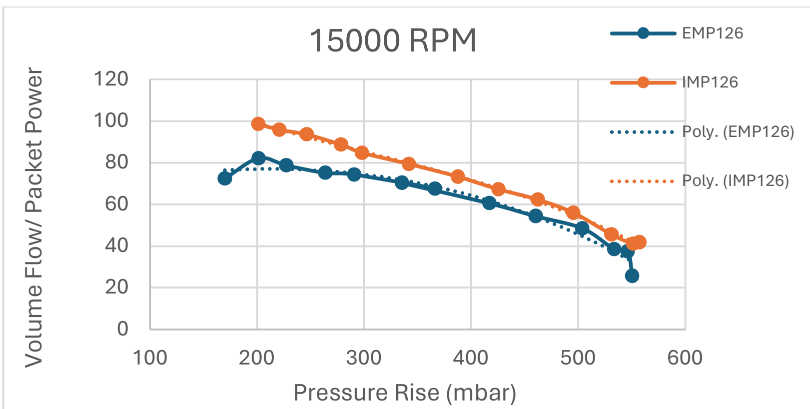

Fig. 1. Pressure Rise vs (Volume Flow/Packet Power) at 15000 rpm

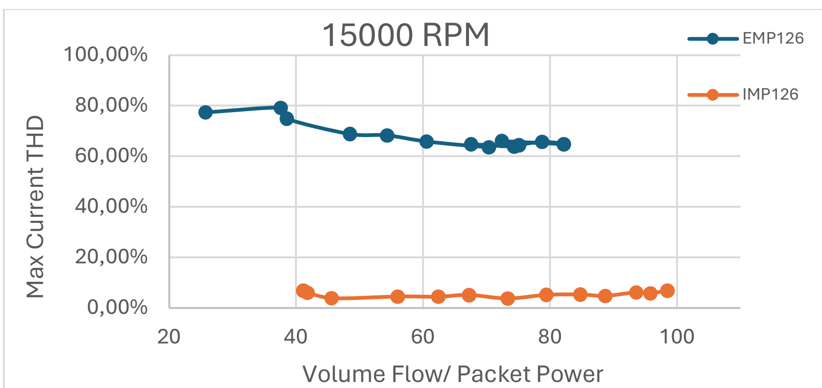

Fig. 2. Volume Flow/Packet Power vs Max Current THD at 15000 rpm

For both machine models, the flow rate per 1 kW was illustrated based on specific pressure rise values at certain RPMs. The efficiency of this study at 15000 rpm is shown in Figure 1. Additionally, graphs depicting the flow rate per 1 kW and THD values were generated. In Figure 2, the graphs illustrating the flow rate per 1 kW and THD values at 15000 rpm can be observed. These visual representations provide valuable insights into the relationship between flow rate, power consumption, and THD levels, aiding in the optimization of the turbo blower systems for enhanced efficiency and performance.

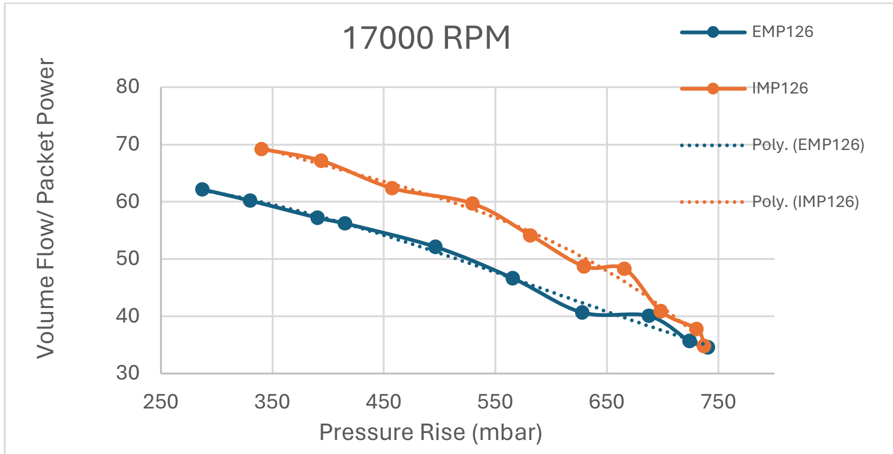

Fig. 3. Pressure Rise vs (Volume Flow/Packet Power) at 17,000 rpm

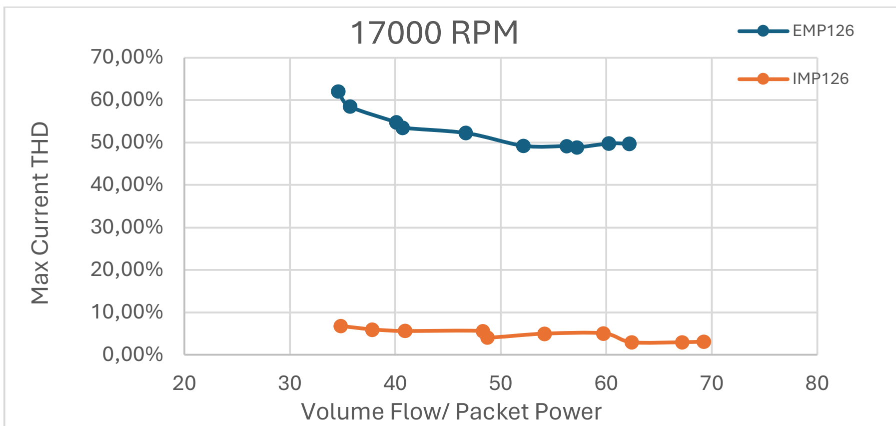

Fig. 4. Volume Flow/Packet Power vs Max Current THD at 17,000 rpm

As depicted in Figure 3, a comparison at 17000 rpm based on the flow rate provided by 1 kW power reveals that the I series is more efficient. The significant difference in Total Harmonic Distortion (THD) values between the two machines is evident in Figure 4.

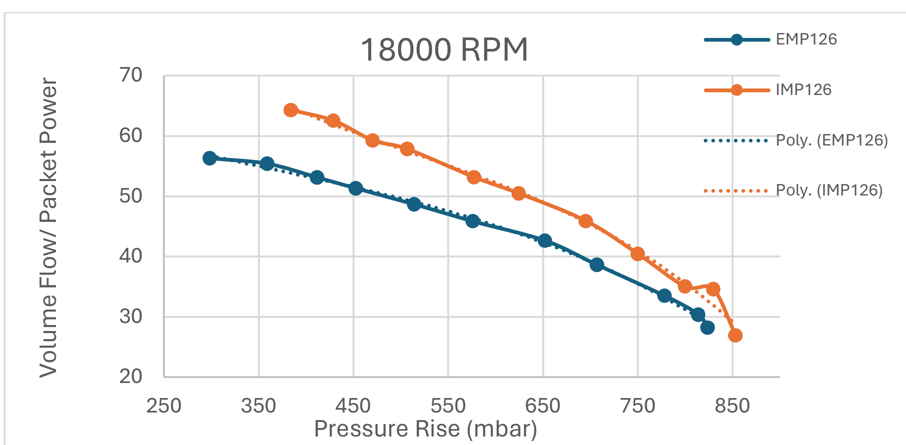

Fig. 5. Pressure Rise vs (Volume Flow/Packet Power) at 18000 rpm

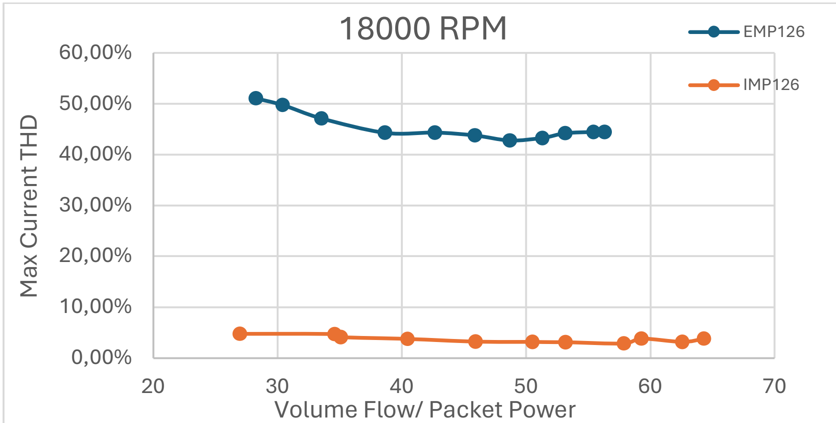

Fig. 6. Volume Flow/Packet Power vs Max Current THD at 18000 rpm

Observing the comparisons based on Total Harmonic Distortion (THD) values in Figures 2, 4, 6, 8, 10, and 12, it becomes evident that the THD value of the I series shows a steadier trend compared to the E series. The E series exhibits a greater degree of variability in this value.

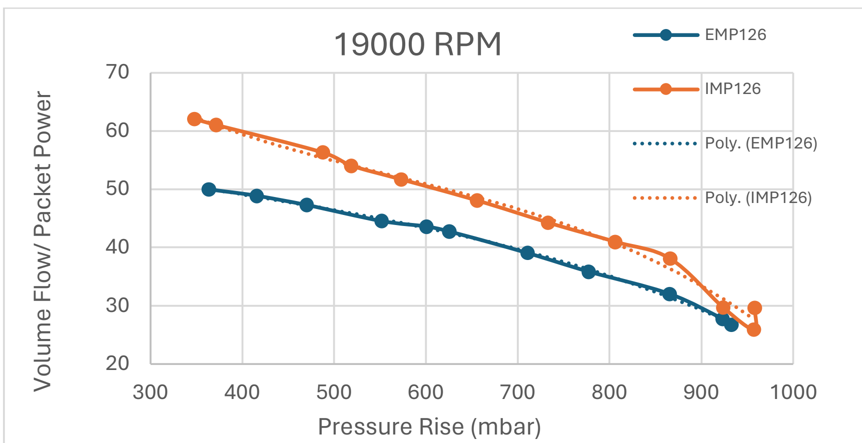

Fig. 7. Pressure Rise vs (Volume Flow/Packet Power) at 19,000 rpm

The efficiency graph for the machine models at 18000 rpm is presented in Figure 5, showing their performance at this specific rotational speed. Notably, the graph reveals insights into the efficiency characteristics of the models under consideration. Moving forward, Figure 7 provides a similar graph, this time focusing on the 19000 rpm value.

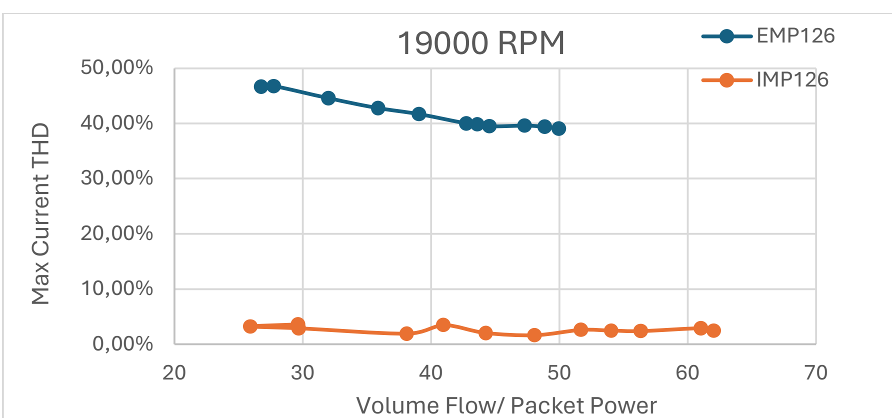

Fig. 8. Volume Flow/Packet Power vs Max Current THD at 19,000 rpm

The graph illustrating the Total Harmonic Distortion (THD) values of the machine at 18000 rpm is presented in Figure 6. The corresponding graph for the 19000 rpm value is depicted in Figure 8.

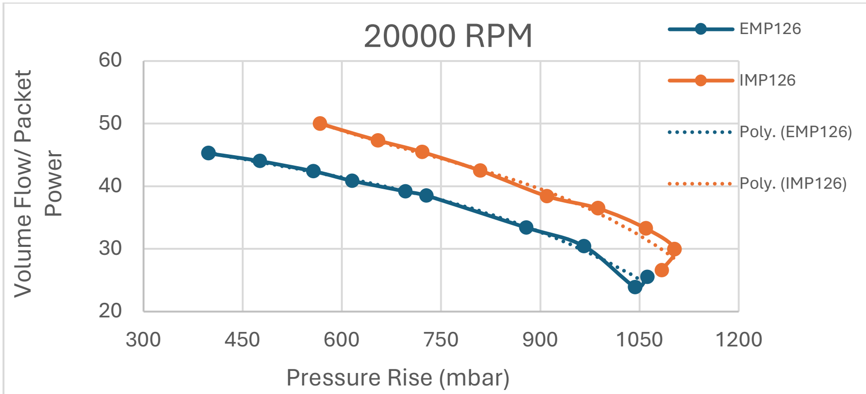

Fig. 9. Pressure Rise vs (Volume Flow/Packet Power) at 20,000 rpm

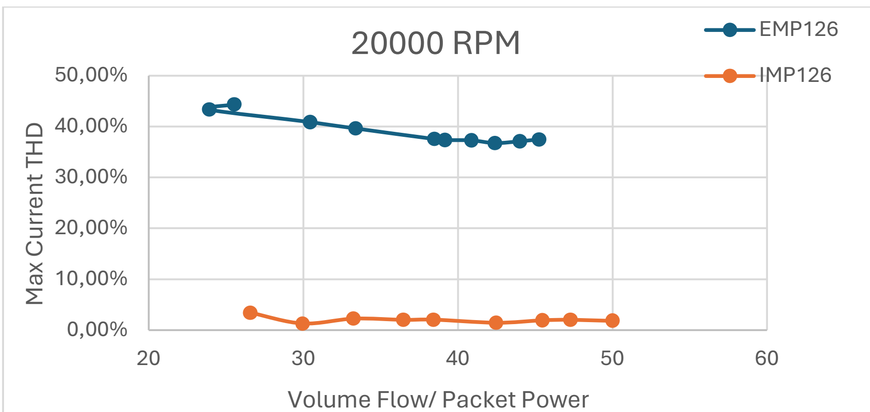

Fig. 10. Volume Flow/Packet Power vs Max Current THD at 20,000 rpm

As evident from the aforementioned graphs, the flow rate per 1 kW at 20000 rpm (Figure 9) and 21000 rpm (Figure 11) is notably higher in the I series when compared to the E series. The noticeable increase in flow rate highlights the I series as a robust performer, showing its capacity to deliver higher output with a consistent power input. This comparative advantage over the E series underscores the I series as a compelling choice for applications where elevated flow rates are crucial.

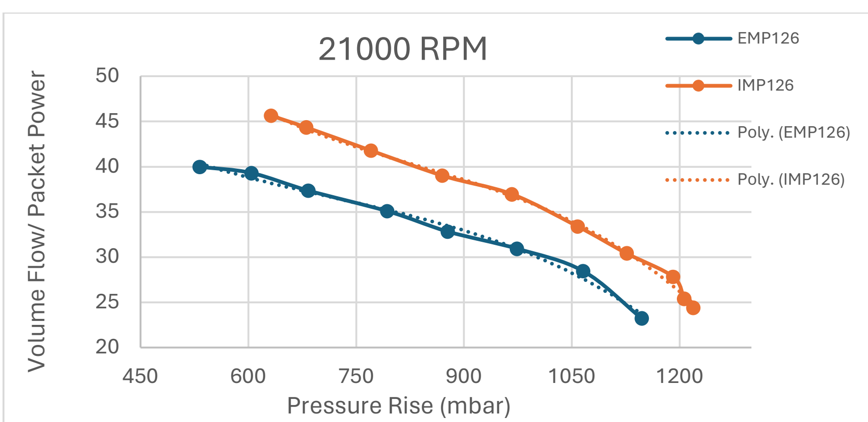

Fig. 11. Pressure Rise vs (Volume Flow/Packet Power) at 21,000 rpm

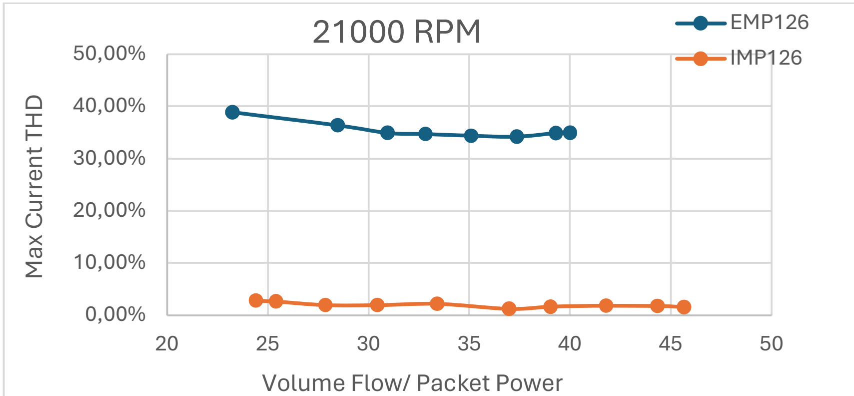

Fig. 12. Volume Flow/Packet Power vs Max Current THD at 21,000 rpm

As seen in the above figures, the I series, showing superior performance in terms of efficiency, not only stands out for its commendable efficiency levels but also distinctly exhibits lower Total Harmonic Distortion (THD) values at 20000 rpm (Figure 10) and 21000 rpm (Figure 12) when compared to the E series. This dual advantage underscores the I series as a more efficient and stable option, emphasizing its potential for applications demanding both high efficiency and low distortion levels. These findings provide valuable insights for optimizing the performance of machine models across varying operational conditions.

Table 2

Annual energy efficiency rate for E and I series machine models

RPM	Energy Efficiency Rate
15,000	25.59%
17,000	19.06%
18,000	17.63%
19,000	18.92%
20,000	23.42%
21,000	18.43%
Avg	20.51%

Analyzing the graphs generated for different RPM values reveals a significantly higher energy efficiency in the I series machines compared to the E series machines (Table 2). Despite the AFE-LCL filter contributing to an increased machine cost, its positive impact on the overall performance is evident, emphasizing the effectiveness of advanced filtering technologies in enhancing energy efficiency. This observation prompts careful consideration of the trade-offs between upfront expenses and long-term operational benefits, providing valuable insights for decision-makers and engineers involved in optimizing the performance and cost-effectiveness of these machines in real-world applications.

4. CONCLUSION

This study concludes with a analysis exploring the influence of THD levels on the efficiency of two magnetic bearing turbo blower models. The study, conducted under identical conditions, highlights the presence of a harmonic reduction filter as the sole distinction between the models. Utilizing an energy analyzer, the analysis delves into power quality, energy consumption, and harmonic distortion values. Experimental data with temperature and pressure readings, supplemented by weather station measurements, provides insights into the efficiency of turbo blowers and the impact of harmonic levels on component temperatures. Critical analysis of key efficiency parameters contributes to optimizing the design and operation of magnetic bearing turbo blower systems. This research advances the understanding of the relationship between THD levels and component efficiency for improved performance and sustainability in industrial applications.

In addition to the current findings, future research in this domain could explore advanced technologies and methodologies to further optimize the mitigation of THD and enhance the efficiency of magnetic bearing turbo blower systems. Investigating innovative harmonic reduction techniques, adaptive filtering approaches, and smart control strategies could offer insights into refining the performance of these systems. There is also a potential possibility for real-time monitoring and feedback systems adjusting harmonic reduction filters based on the operating conditions. Integration of machine learning algorithms could provide adaptive and predictive capabilities, optimizing the efficiency of magnetic bearing turbo blowers under varying loads and operational scenarios. These future directions aim to advance the current research and foster continuous improvement in the design, operation, and sustainability of magnetic bearing turbo blower systems in industrial settings.

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Efectul Nivelului de Distorțiune Armonică Totală asupra Eficienței în Suflantă Turbo

Rezumat: *Acest studiu prezintă o analiză comparativă care investighează impactul nivelurilor de distorsiune armonică totală (THD) asupra eficienței a două modele de suflante HAUS Turbo cu rulmenți magnetici. Ambele modele funcționează în condiții și setări de încărcare identice, singura diferență fiind prezența unui filtru de reducere armonică într-unul dintre ele. Analiza implică examinarea calității energiei, a consumului de energie și a valorilor distorsiunii armonice folosind un analizor de energie. Datele experimentale sunt colectate din diferite puncte de pe turbosuflante și completate de măsurători ale stațiilor meteorologice. Accentul se pune pe consumul de energie, valorile armonice și temperaturile componentelor, în special motorul și unitatea de frecvență variabilă (VFD). Sunt analizați parametrii de eficiență, cum ar fi eficiența politropică și consumul specific de energie, oferind informații despre relația dintre nivelurile THD și eficiența componentelor. Această cercetare are ca scop optimizarea parametrilor de proiectare și funcționare a sistemelor turbosuflante cu rulmenți magnetici.*

Cuvinte cheie: *THD, eficiență energetică, suflantă turbo, putere pachete, debit volumic, creștere presiune*

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