

Improving Energy Efficiency in Metalworking Machine Tools: Vector Control of Electric Drives Using a Frequency Converter and System Modeling

Sardorjon Samiev^{*1}, Shokhabbos Doliev¹, Farrukh Juraev², Sunnatjon Farxodov¹, Ramziddin Toshtemirov¹

¹Department of Information Technologies in Industry and Tourism, Shahrizabz Faculty of Food Engineering, Karshi State Technical University, Shahrizabz 181306. Uzbekistan.

²Department of Economics, Faculty of Pedagogy, University of Economics and Pedagogy, Karshi 180100. Uzbekistan.

*Corresponding author: sardorjonsamiyev95@gmail.com

INTRODUCTION & AIM

In modern mechanical engineering, there is an increasing demand for automated and intelligent drive systems that reduce dependence on maintenance personnel and enhance operational efficiency. This trend drives the development of advanced automated electric drive technologies capable of ensuring reliable and adaptive machine operation under varying load conditions.

In machine tool engineering, there is a clear shift toward the use of universal metal-cutting machines equipped with variable-speed electric drives. The implementation of asynchronous motors with frequency converters enables stepless speed regulation, which significantly improves process flexibility and energy efficiency. Recent advancements in controlled electric drive systems have resulted in solutions characterized by high reliability, long service life, improved performance, and reduced cost. Moreover, such technologies simplify mechanical transmission systems by reducing or completely eliminating complex gearboxes and feed mechanisms.

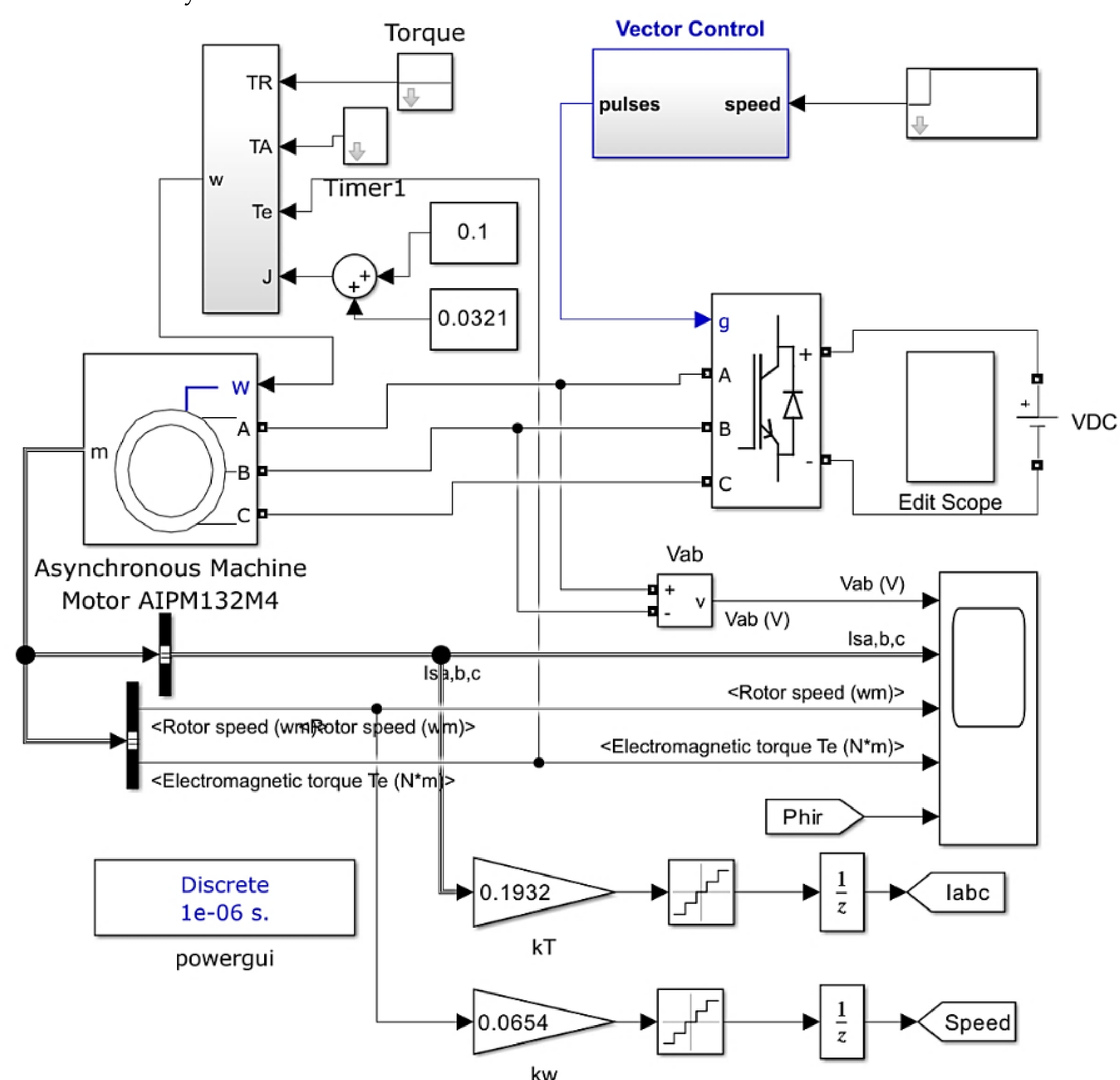
Lathe machines remain one of the most important equipment types in manufacturing industries. They are widely used for processing cylindrical workpieces and performing essential operations such as external turning, internal boring, threading, drilling, and countersinking. The spindle serves as the main functional element of the lathe, responsible for providing rotational motion to the workpiece during machining.

Aim of this work is to improve the performance efficiency of the 1K62 lathe machine through modernization of its electric drive system. This study focuses on the implementation of an asynchronous motor controlled by a frequency converter using vector control strategy. The proposed approach ensures precise spindle speed regulation, stable torque at low speeds, reduced energy consumption, and improved stability of the cutting process.

METHOD

The modernization focuses on improving energy efficiency, operational reliability, and control performance of the lathe drive system. The existing motor A61-4F2 (10 kW) is replaced with a higher-efficiency induction motor AIR M132M4 (11 kW), combined with a modern Schneider Electric Altivar ATV71HD11N4 frequency converter.

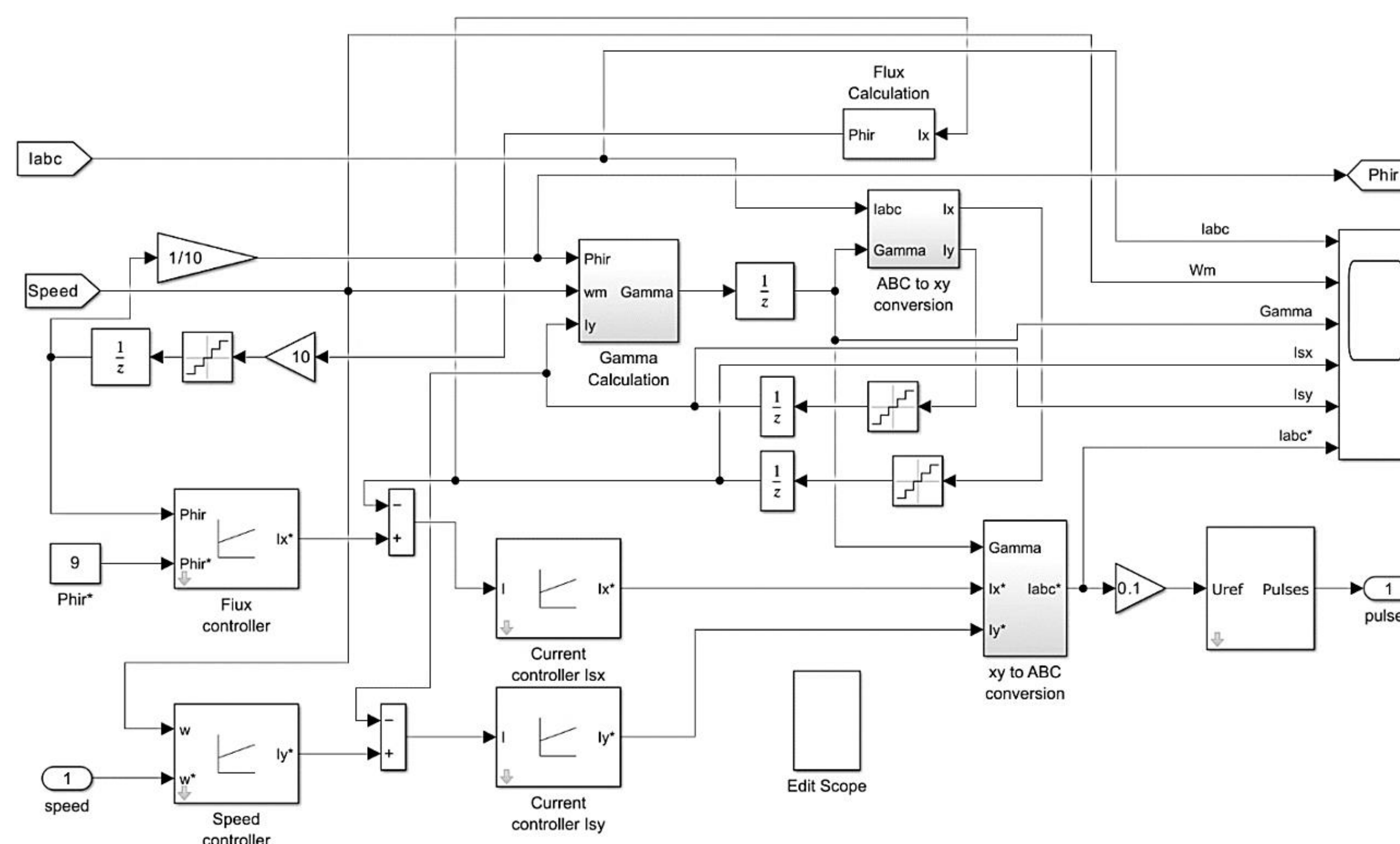
In the course of the work, a mathematical model of the electric drive with vector control was developed. The mathematical model includes a squirrel-cage induction motor (SCIM), a frequency conversion device (inverter), a power supply unit for the inverter, as well as a vector-type control system. This makes it possible to perform calculations aimed at determining the speed characteristics of the system in coordinate form, the frequency parameters of the inverter, as well as the structural forms of the components within the electric motor system.



The central role in the structure of the electric drive (ED) is occupied by the vector control mechanism, a component of which is a subsystem.

The vector-controlled SCIM drive uses measured stator currents and rotor speed to estimate angular velocity (ω_k) and rotor position (γ). Current regulators generate reference signals in a two-phase coordinate system, which are converted to three-phase form using the XY-ABC transformation block.

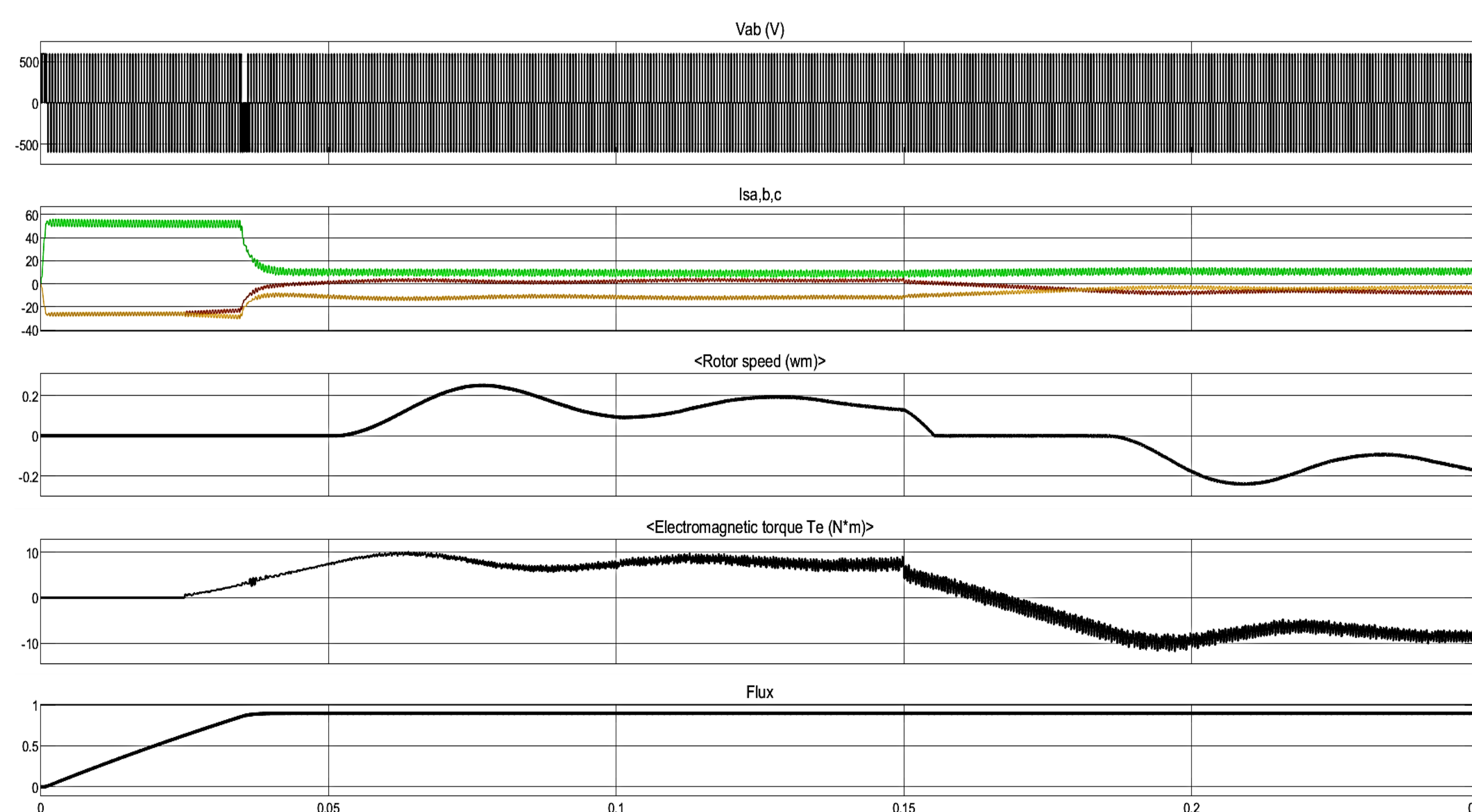
A voltage source inverter (VSI), controlled by a microprocessor-based PWM system, regulates output voltage and frequency through transistor switching. The drive operates in a closed-loop structure where feedback currents are continuously compared with reference values to ensure stable and accurate performance under variable load conditions.



RESULTS & DISCUSSION

The vector-controlled electric drive shows stable and satisfactory performance during start-up based on the obtained results. It operates effectively at low speed and light load conditions, ensuring the required speed reference and quickly restoring the set speed after load disturbances.

The analysis confirms that vector control provides high accuracy in speed and torque regulation, as well as good dynamic response. Overall, this method is well-suited for applications requiring precise and stable electric drive control under varying operating conditions.



CONCLUSIONS

The study confirms that modernizing the 1K62 lathe electric drive with a frequency converter and vector control improves energy efficiency and operational performance. The system ensures precise speed control, stable low-speed torque, reduced starting current, and lower energy consumption.

The mathematical model demonstrates stable motor operation under start-up, load changes, and reversal conditions, with improved dynamic response.

Compared to scalar control, vector control provides higher accuracy, smoother operation, reduced vibration, and better machining stability. The use of the AIR M132M4 motor and Schneider Electric Altivar ATV71HD11N4 converter further increases efficiency and reliability.

Overall, vector control significantly enhances drive performance and is an effective solution for modern machine tool applications.

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