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The Effect of Steel-Core Choke on the Performance of a Single-Phase Universal Motor

Abstract: - This study presents a robust robotic system designed to automate the feeding of lightweight components into appropriate machining centers. These centers utilize single-phase handheld power tools, each equipped with specific cutting implements and powered by a single-phase universal motor with rated power of 1.125 kW operating on AC voltage. A notable characteristic of these universal motors is their power supply through a three-phase converter. The research proposes an experimental methodology to evaluate the impact of incorporating a steel core choke on the performance of each universal motor. An inductance, with specific parameters of 2.32 mH, is connected between the three-phase converter and the single-phase universal motor. This inductance also functions as a positive current feedback mechanism. The system's robustness is enhanced through current and voltage feedback connections to and from the single-phase universal motors, improving the control of each universal electric motor.

Keywords: variable frequency drive (VFDs), robot Fanuc M-430iA/4FH, universal motor (UM), ACS55 - micro drive, steel core choke, pulse width modulation (PWM)

I. Introduction

Frequency converters, also known as variable frequency drives (VFDs) or inverters, are widely used in industrial applications to control the speed and torque of electric motors by adjusting the frequency of the electrical supply, [1]. The performance of a frequency converter, particularly in terms of output voltage stability and efficiency, is influenced by several parameters, including the inductance within the circuit, [2]. Inductance, which opposes changes in current, plays a critical role in determining how smoothly the voltage is converted, as well as the overall power quality of the system. Understanding the effect of inductance on the output voltage of a frequency converter is essential for optimizing performance in applications ranging from motor drives to renewable energy systems.

In a frequency converter, inductance is typically introduced by the motor winding, input filters, and additional inductive components in the circuit. The presence of inductance affects the current waveform, leading to variations in the output voltage and impacting both the harmonic content and ripple voltage. This behavior arises because inductance resists changes in current, causing a delay in the current response relative to the voltage, and thus leading to phase shifts and potential energy losses. The degree to which inductance affects the output voltage depends on factors such as the converter's switching frequency, load characteristics, and the total inductance in the system.

The integration of additional inductance into the circuit of a frequency converter can significantly influence the output voltage, impacting the overall performance and efficiency of the system. Frequency converters, which are pivotal in various applications such as renewable energy systems, motor drives, and power supplies, rely on precise control of voltage and current to function optimally. The role of inductance in these systems is multifaceted, affecting aspects such as voltage gain, efficiency, and electromagnetic interference (EMI).

Inductance in a circuit can be introduced through various components, including transformers, coupled inductors, and additional inductors in the design. For instance, the inclusion of a high-frequency transformer in an LCL-type DC-DC converter introduces magnetizing and leakage inductances, which can alter the converter's performance, especially under varying input voltage and load conditions, [3]. Similarly, the use of coupled inductors in DC-DC converters can enhance voltage gain and efficiency while managing voltage stress across semiconductor components, [4, 5].

The design and optimization of inductive components are crucial for achieving desired performance metrics. Furthermore, the introduction of additional inductance can also address specific challenges in converter design. In a bridgeless SEPIC converter, adding an inductor and an output diode can eliminate undesired capacitive coupling loops and circulating losses, thereby enhancing efficiency, [6]. Similarly, in LLC resonant converters, variable

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magnetizing inductance control (VMIC) strategies can be employed to maintain a fixed switching frequency, thereby improving efficiency and reducing EMI, [7].

In this context, analyzing the effect of inductance on the output voltage of frequency converters is essential for the development of more efficient and reliable systems. By adjusting the inductive elements and controlling switching frequencies, engineers can minimize voltage fluctuations, reduce losses, and improve power quality. This study seeks to explore how variations in inductance impact output voltage characteristics in frequency converters, offering insights that are crucial for applications in motor control, power generation, and energy management systems.

II. Experimental Results and Discussion

An electrical circuit has been designed to control a robotic system to ensure the operation of a Fanuc M-430iA/4FH robot, which is engineered to retrieve workpieces from a conveyor, transfer them, and feed lightweight components for machining to various machining centers such as broaching and threading, Fig. 1. The system incorporates an electrical cabinet from which the operation of three machining centers is regulated. The machining centers utilized are single-phase hand-held electric machines based on universal electric motors (1.125 kW) controlled by three three-phase frequency converters - type ACS55. Subsequently, the frequency converters regulate the single-phase universal machines utilizing the pulse width modulation (PWM) method.

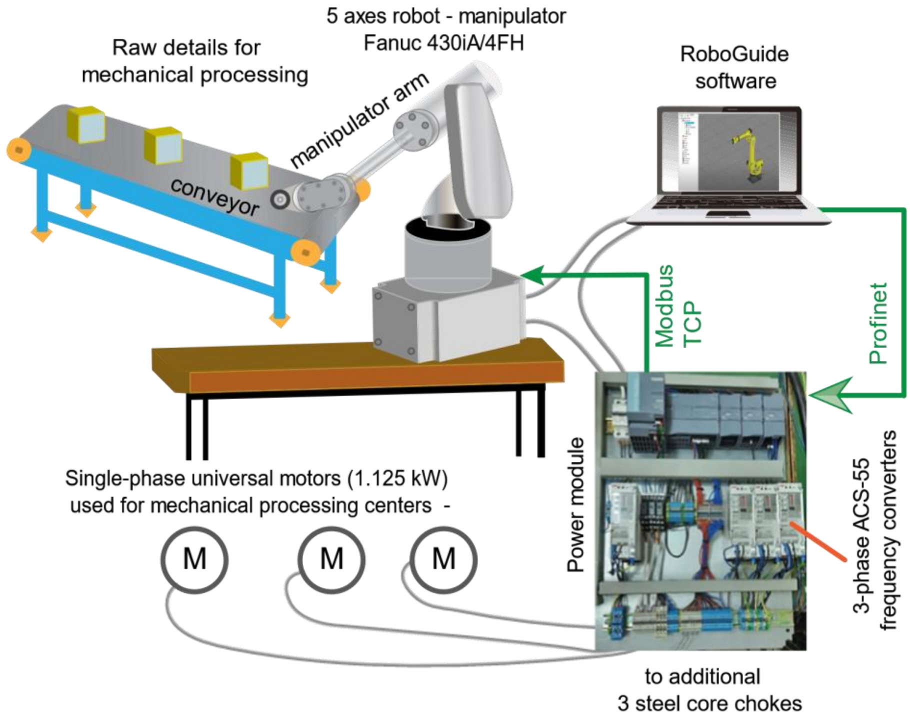


Figure 1. Schematic diagram of the operation of a robotic system for machining light workpieces with robust control, based on the Fanuc M-430iA/4FH Robot, [8].

Universal motors exhibit different performance characteristics when operated on AC versus DC supply, affecting parameters such as speed, torque, efficiency, and electromagnetic radiation, [9]. In the current investigation, three universal motors are powered by alternating current (AC) supply through ACS55 converters. The shape and quality of the supply voltage are critical factors for the efficient operation of the universal machines. When utilizing AC supply, it is advisable that the voltage remain stable with minimal harmonic distortion and perturbation. Harmonics in the supply voltage can lead to increased losses, noise, and thermal stress in motors, which can degrade performance and reduce lifespan, [10-12].

The performance of universal motors can be significantly affected by the characteristics of the supply voltage, particularly when it contains harmonics. Harmonic supply voltage affects the speed, current, and torque waveforms of universal motors, with induced voltage in the rotor being influenced by magnetic core saturation according to Záskalický et al., [13, 14].

It is well known that harmonics generated by power electronic devices, such as PWM inverters, as used in this article, can lead to increased total harmonic distortion (THD) in both voltage and current, which can exceed the IEEE standard 519 limit of 5%, [15, 16].

Based on the literature review conducted on the performance of universal electrical machines and the identified issues regarding the shape and quality of their voltage supply, it is evident that additional devices should be implemented to enhance the supply voltage shape.

Aihsan et al. examine how various inductor types, including drum core and toroidal core, can influence the performance of single-phase inverters in converting unfiltered AC voltage into filtered sinusoidal AC voltage, [17]. Additional methods are proposed in the literature to effectively reduce electromagnetic interference (EMI) and enhance performance in inverter systems and motor applications through the introduction of a ferrite core choke, [18-20].

This study suggest that the insertion of inductivity with a steel core affects the performance of single-phase universal motors driven by ACS-55 inverters by influencing iron losses, motor characteristics, and control performance.

This study employs an experimental approach to implement an electrical circuit utilizing an additionally introduced steel-core choke at the output of a three-phase frequency converter, with the objective of enhancing the waveform and, consequently, the quality of the supply voltage for powering single-phase universal electrical machines.

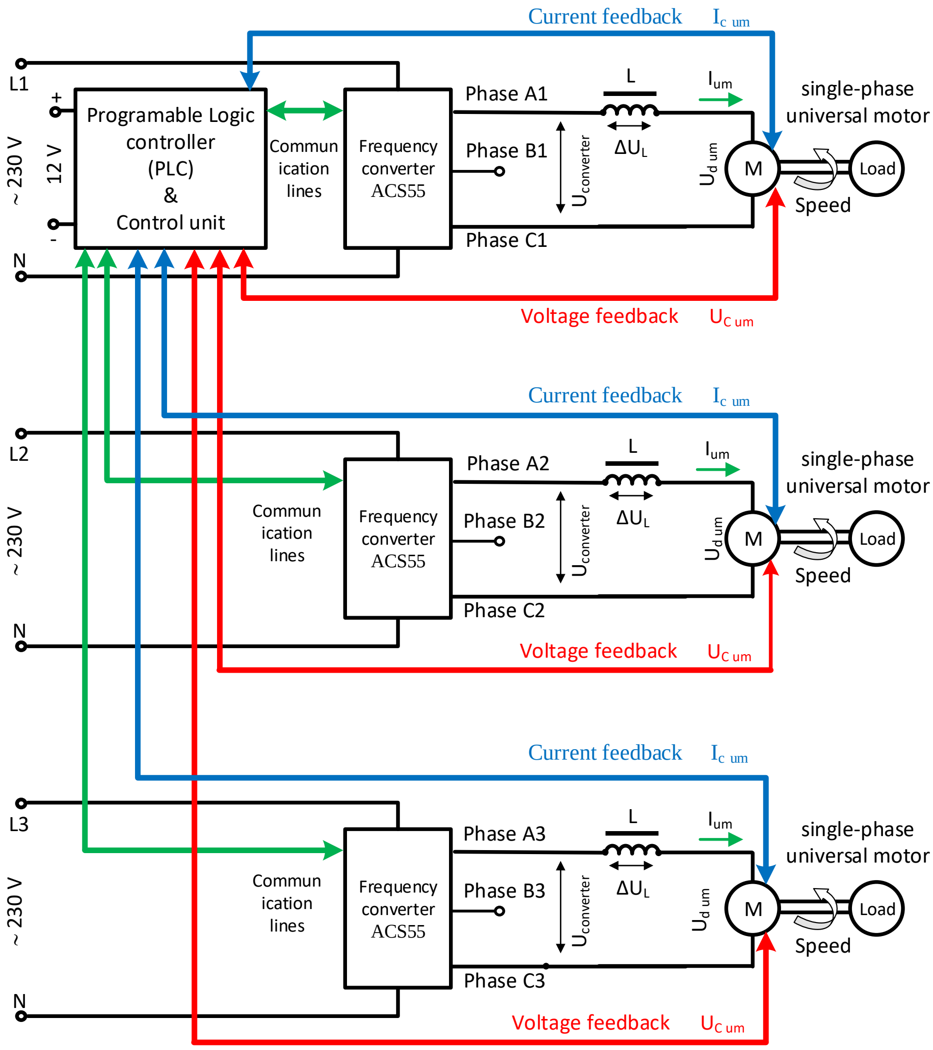


Figure 2. Schematic representation of a control cabinet for a robotic system and power supply of three single-phase universal motors with a rated power of 1.125 kW

The designed electrical circuit is intended to regulate the velocity of a universal machine equipped with an apparatus for machining lightweight workpieces. A distinctive feature of the implemented scheme is the operation of three three-phase converters, which are utilized to regulate the velocity of single-phase universal machines.

Stable operation of universal machines is ensured by incorporating additional chokes at the output of each converter, which subsequently stores electrical energy and influences the waveform of the supply voltage, thereby reducing the level of harmonic distortion. Steel core chokes are essential components in electrical circuits, particularly in AC motor drives and other applications requiring the management of electromagnetic interference and energy storage. Therefore, the inductance introduced is a choke with a steel magnet conductor, and an inductance value of 2.32 mH at a voltage of 230 V, and a calculated and implemented air gap of 3 mm, **Error! Reference source not found.** The introduced inductance contributes to the creation of a magnetic field with constant parameters, which consequently reduces arcing between the brushes and the machine collector.

The precision control of single-phase universal motors is implemented through the utilization of positive feedback in current ($I_{c\ um}$) and voltage ($U_{c\ um}$), as illustrated in Fig. 3. Current feedback is achieved via a current sensor that responds to the resistive torque of the machine. This sensor transmits a digital signal to the control unit, which subsequently influences and modifies the pulse-width modulation of the converters if necessary. Voltage feedback is implemented through a voltage sensor that monitors the universal machine voltage. Upon the occurrence of a mechanical load, voltage signals are transmitted to the control unit to adjust the voltage supplied to the universal motor.

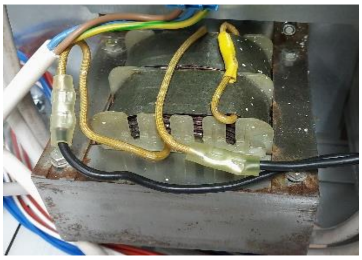
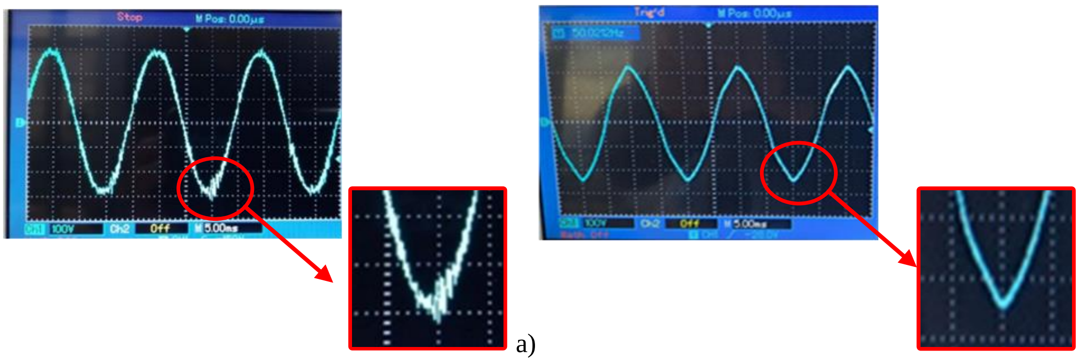


Figure 3. Photographic representation of the utilized choke, featuring a steel core and an inductance value of 2.32 mH, employed to enhance the voltage waveform supplying a single-phase universal motor

The electrical energy stored in the inductors mitigates impulse disturbances, which consequently reduces the insulation life of the electrical machine. The design parameters of the choke are calibrated to correspond with the power of the frequency converter and the electrical machine. It is advisable to establish the inductance with a 20% margin to ensure a reduction in interference and harmonic distortion. Empirically obtained results demonstrate that the addition of inductance at the output of a frequency converter operating in the asymmetrical mode exerts a beneficial effect on its performance; specifically, the inductance functions as a positive feedback mechanism on the current.

Oscillograms of the voltage supplied to the universal motors in the absence and presence of a choke with the previously determined parameters in the electrical circuit were obtained experimentally, as illustrated in **Error! Reference source not found.**



a)

Figure 4. Oscillograms of the supply voltage applied to a universal electric motor with a power rating of 1.125 kW: a) without a choke; b) with a choke of 2.32 mH inductance present.

In the absence of a choke in the circuit, specifically when the universal motors are directly powered by the frequency converter, numerous deviations from a sinusoidal waveform are observed in the voltage oscillogram. These deviations indicate the presence of undesirable interference, which contributes to the degraded and unreliable operation of universal motors, **Error! Reference source not found.**a. The incorporation of a steel-core choke in the electrical circuit between the frequency converter and the universal motor, **Error! Reference source not found.**b, results in the attenuation of deleterious sinusoidal deviations, thereby ensuring optimal motor performance.

III. Conclusions

This paper proposes a novel approach to address the existing problem of direct feeding of universal motors using frequency converters. In conclusion, based on experimentally conducted studies on the utilization of a steel core choke in a universal motor power supply, it can be ascertained that the quality and shape of the voltage contribute to the reduction of harmonic distortion and impulse disturbances, thereby extending the operational lifespan of the universal motor and mitigating the risk of failure. Effective operation of universal motors has been achieved through the implementation of digital current and voltage feedback, thus attaining robustness in motor control. The operation of a three-phase frequency converter, implemented as a single-phase unit, to regulate the speed of a single-phase universal motor is atypical and is characterized by the additional requirement of introducing a choke with specific parameters. This study suggests that the insertion of an inductive component with a steel core between an ACS-55 inverter and a single-phase universal motor can enhance the power factor, diminish the harmonic content, and improve power efficiency.

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