Suggestions on the Training of CNC Machine Tool Installation, Adjustment, and Maintenance Technicians and Senior Technicians

Authors: Hongfeng Zhu, Zhu Hongfeng

Date: 2022-08-24T00:00:00+00:00

Abstract

This article, by integrating relevant policies, guidelines, and requirements for enhancing workers' employment and entrepreneurship capabilities, improving skills training quality, and accelerating the cultivation of a large contingent of knowledge-based, skilled, and innovative high-skilled labor force, proposes suggestions and methods for the digital transformation of training programs for CNC machine tool installation, adjustment, and maintenance technicians and senior technicians from the perspectives of task analysis, methodology research, competency development, technical connotation analysis, training problem resolution, and key teaching implementation steps.

Full Text

Introduction

Some Thoughts on the Training of CNC Machine Tool Installation, Adjustment, and Maintenance Technicians and Senior Technicians

Song Haihui, Wu Xiaotao, Zhu Hongfeng
Shanghai Second Polytechnic University, Mechanical Industry Vocational Ability Evaluation Examination Station 222

Keywords: CNC machine tool installation and maintenance; state/event analysis; capability construction

Since 2018, the State Council and the Ministry of Human Resources and Social Security have issued documents Guofa [2018] No. 11 [1] and Renshebufa [2018] No. 74 [2], signaling strong policy direction for alleviating talent supply-demand contradictions and improving employment quality. In response, the Ministry of Education' s *National Vocational Education Reform Implementation Plan* (2019-2021) [3], the State Council General Office' s *Vocational Skills Improvement*

Action Plan (2019-2021) [4], and the Ministry of Human Resources and Social Security' s *Vocational Skills Improvement Action Plan (2019-2021)* [5] were successively released. Complementing these initiatives, the Chinese Mechanical Engineering Society' s *China Mechanical Engineering Technology Roadmap* [6] and the China Machinery Maintenance Association' s *Equipment Management and Maintenance Roadmap* [7] have established clear requirements: CNC application teaching, particularly practical training components, must employ more advanced and comprehensive methodologies and technical platforms to ensure students acquire practical, cutting-edge, and era-appropriate knowledge and skills [8].

Task Analysis

The primary mission of our mechanical industry vocational ability evaluation examination station is to closely track the latest technological developments in the field and build upon existing occupational standards and training methodologies from the Ministry of Human Resources and Social Security to pioneer new approaches. Our goal is to cultivate a new generation of technical and managerial talent who possess not only equipment and systems expertise but also management acumen and socioeconomic awareness, all underpinned by superior comprehensive capabilities and professional integrity.

To achieve this, we must first deepen our understanding of fault maintenance technology by introducing theories that reveal the fundamental nature of electromechanical equipment failures and promoting diagnostic methods amenable to digital solutions and human-machine collaboration. This will enable more effective and rapid capability development. This proposal advocates leveraging the inherent and unified logical relationships among the diverse vocational competencies required for CNC machine tool installation and maintenance to develop an interdisciplinary, cross-professional, yet methodologically coherent digital training framework. While specific implementation strategies are being progressively rolled out and will be detailed in subsequent publications, we first outline our proposed methodological approach.

Methodological Research

First, CNC machine tool installation and maintenance constitutes meticulous technical work involving complex engineering problem-solving. Practitioners require foundational skills and equipment operation experience, with comprehensive capabilities enabling them to decompose complex electromechanical engineering problems into discrete technical issues containing singular technical contradictions, which can then be systematically resolved. General competency requirements encompass holistic cognition of electromechanical system design, manufacturing, and operation/maintenance processes. Professional competencies include the ability to analyze relationships between equipment states and events during operation and to model state transition processes, as well as the capacity to construct electromechanical systems using specific mechanical-electrical structures and control models or to ensure normal equipment operating conditions.

Second, CNC machine tool fault diagnosis and maintenance represents the "inverse process" of development and design. Development design is a system construction process based on known objectives and constraints, requiring analysis of target processes, deduction of equipment construction and operation procedures, and resolution of whole-process issues spanning task scheme design, product planning, conceptual design, configuration design, and manufacturing process design. Conversely, fault diagnosis and maintenance involves orderly analysis of dynamic systems that have unexpectedly entered disordered states—determining critical operational states or tracing key events based on known system outputs and processes to identify fault locations and root causes. This demands robust inductive integration capabilities.

Third, the logical relationships between process conditions and outcomes are unified across system analysis, synthesis, deductive construction, state process refinement, induction, and state/event tracing. In essence, the research methodologies for development design and fault diagnosis/maintenance are unified. State/event analysis methods [9] can be introduced and flexibly applied to examine these unified logical relationships. When such analysis integrates mechanical, electrical, and software control knowledge while bridging theory and practice, it can address technical innovation challenges—such as structural improvements to overcome deficiencies or meet new requirements, green manufacturing issues, or even the development of innovative product variants through digestion and absorption of advanced core technologies, potentially yielding inventions. By altering known conditions and target problems, the same approach can resolve equipment abnormal state analysis, fault localization, and solution determination—namely, fault diagnosis and maintenance problems. Consequently, vocational capability training for CNC equipment operation and maintenance can focus on two core competencies and one professional competency.

Core Competency Training:

Deductive Construction Capability: This involves applying deductive reasoning to analyze engineering problems in mechanical system design, identifying constituent technical issues, organizing technical link action sequences along system operation logic, and employing virtual or physical technical means to resolve problems individually before integrating solutions into comprehensive engineering resolutions. General capability training is thus embodied as deductive construction capability training.

Inductive Integration Capability: This employs integrative thinking to establish logical models of system operation, deeply understanding the state transition processes and trigger events necessary for normal system functioning. By systematically comparing designed versus actual operational processes, abnormal processes or states can be identified. Through whole-process cyclic reflection, technical problems in dynamic processes can be pinpointed to locate faults or determine optimization solutions. Comprehensive capability training is thus embodied as inductive integration capability training.

Professional Capability Training:

This encompasses specific digital technology applications using modern engineering tools, including electromechanical structure modeling, logical modeling, analysis, simulation, visualization programming, and industrial networking. These competencies manifest as the knowledge and skills acquired by students during general and comprehensive capability training, alongside gradually developed safety consciousness, standardization awareness, and rigorous engineering habits and discipline.

For higher vocational education students (both college and undergraduate levels), this core and professional capability training complements relevant occupational standards while simultaneously satisfying Ministry of Education engineering certification requirements, making it suitable for "1+X" teaching upgrades in higher education institutions [10]. For on-the-job technicians and senior technicians seeking advancement, this training aligns with their established technical cognition and engineering habits, while modeling exercises help them steadily integrate digital technologies atop their existing skill foundations.

Problems in Skills Training

Common faults are classified as either deterministic or random based on manifestation, and as mechanical or electrical based on location. Conventional diagnostic methods include comparison, interchange, dimensional adjustment, state observation, parameter setting, alarm query, and case analysis. While trainees should ideally practice each method, limited training hours and resources make it impossible to cover all techniques comprehensively. Practical examinations similarly focus only on typical deterministic faults, as random faults are difficult to reproduce.

In production environments, the lengthy application processes of these methods are condensed into case records. When faults recur, technicians can efficiently troubleshoot by matching phenomena to documented solutions. Over time, skill levels become measured by troubleshooting efficiency. Consider the CNC tool turret: as a universal device, its common faults are well-documented, with traditional maintenance methods having produced comprehensive case libraries covering dozens of scenarios such as no tool change action, incomplete tool search, or ineffective locking.

Each case specifies detailed inspection scopes and methods. Maintenance personnel can readily retrieve diagnostic procedures by matching fault phenomena. For instance, if tool change fails to initiate, technicians check whether the tool change command executed, relay/contactor circuit power status, circuit integrity, component operation, and motor blockage. For locking failures, they verify motor reversal, reversal duration, stop pin positioning, and lock nut position.

However, high-end CNC lathe and machining center tool magazines—complex, proprietary auxiliary devices—feature manufacturer-specific operation, monitoring, and diagnostic methods, often requiring dedicated software/hardware tools. Troubleshooting these devices typically demands strict adherence to original technical documentation; without guidance or comparable references, technicians may face arduous trial-and-error analysis.

Consider these examples: A Siemens servo motor exhibits excessive no-load power consumption after encoder replacement, functioning abnormally without alarms or showing zero-mark loss requiring commutation angle recalibration; a FANUC cylindrical grinder experiences headstock oscillation due to improper belt pretension; a domestic CNC machine' s separate spindle encoder connection looseness causes noise and heating at high speeds without detectable mechanical faults. Such issues often lack documentation yet, through case summarization, reveal common root causes within encoder feedback control loops.

These scenarios illustrate a shared challenge: advanced CNC equipment often presents fault phenomena that stump certified technicians, leaving them unable to apply trained skills and feeling that experience accumulation offers no immediate solution. The following exploration demonstrates how deep investigation of fault diagnosis technical connotation can yield answers.

Technical Connotation Analysis

Automated electromechanical systems execute predetermined tasks through specified process steps, each maintaining a defined working state or transient process (e.g., constant value, increment, decrement, or monotonic function variation). Externally, the system transitions from initial to subsequent states upon step completion. This state migration resembles an event occurring at the transition moment—a state transition event that alters system operation. This constitutes the logical relationship between process states and transition events. State/event analysis effectively models complex dynamic logic processes from an external perspective, making it a powerful engineering methodology.

From this viewpoint, system states and events can be conceptualized as sets. Complete state and event sets encompass both normal and fault conditions, with fault state sets being complements of normal state sets. Normal system dynamics follow designed state/event sets in an orderly fashion, whereas fault events and states fall outside pre-designed sets, appearing disorderly. Equipment without prior faults has empty fault state/event sets and uncertain fault processes. However, once a fault occurs and is resolved, the fault sets become populated with a determined transition event and corresponding fault state, along with clear positioning information within the normal state sequence. This enriches the system' s complete operational state/event sets—a process mirroring technician experience accumulation. Original technical documentation essentially represents manufacturers' pre-summarized common problems that partially populate these sets. State/event analysis thus brings both orderly normal processes and disorderly fault processes under unified, systematic investigation.

Key to Training Reform Success

Automated electromechanical systems integrate mechanical, electrical, and automation control technologies, making state/event analysis inherently multidisciplinary. As established, complete system operational knowledge accumulates gradually through usage. New advanced equipment' s journey from commissioning to stable production incorporates frontline technicians' collective wisdom. Therefore, mastering state/event analysis benefits both practicing maintenance personnel and students. Yet training remains constrained by limited hours and resources, and exam-oriented trainees can easily pass tests by memorizing question banks. Can reform succeed despite these challenges?

The key lies in employing digital simulation for assisted deduction and virtual debugging. Digital electromechanical models clearly reveal static structures and dynamic processes that are physically unobservable. Combined with virtual debugging of digital logic models, they can artificially expose potential fault states and trigger events, enabling rapid acquisition of fault prevention and diagnostic rehearsal experience. Only when trainees deeply comprehend technical connotation will these constraints dissolve, ensuring reform success.

Reflecting on earlier examples, experienced technicians can rapidly identify likely fault locations—such as which tool change step may fail, which tool magazine condition signal is absent, or which servo control link may experience parameter degradation—upon observing fault scenes. They can predict causes and locate faults within structural and logical processes to guide efficient troubleshooting. Through digital simulation, graduates and aspiring technicians can better understand equipment principles and operation, master essential traditional methods, and accumulate experience before encountering real faults, approaching veteran efficiency in practice.

In summary, state/event analysis combined with digital simulation transcends individual structural, operational principle, or control process analyses, as well as their comprehensive integration. Its primary advantage lies in analyzing dynamic logical condition sets and all conditions leading to abnormalities.

Key Teaching Steps

First, emphasize digital twin training: grasp both virtual and reality firmly. **Step one:** Have physical objects in view—develop preliminary cognition of physical electromechanical structures from reality. **Step two:** Have models in the computer—create digital models through iterative validation to ensure faithful representation of physical structures, working states, events, and processes. These models must support arbitrary observation, disassembly, trial operation in virtual environments, and even virtual-real joint debugging via industrial networks. **Step three:** Have models in the mind—this model represents the mental projection of all physical, principle, and process details. In any environment (real or virtual), any observed detail should immediately map to this mental model, enabling mental deduction or thought experiments to predict subsequent conditions. **Step four:** Return to reality—close the loop by verifying understanding against implementation, organizing and adjusting as needed.

These four steps constitute the progression from engineering experience accumulation to habit formation. Familiar to seasoned practitioners, they are crucial for achieving core and professional capability objectives. The cycle must be repeated multiple times: first following online course sequences, then independently designing or analyzing different electromechanical systems. Through iterative, non-linear practice, trainees identify gaps, organize complex logical relationships, and induce general solutions for electromechanical system construction—this is the aforementioned cyclic reflection.

Through such training, CNC operation and maintenance personnel can master the essential logical processes of equipment operation, learning to understand faults realistically, analyze them dialectically and rigorously, and recognize fault essence within specific states, events, and processes. This breaks through traditional maintenance thinking, yielding a unified, generalized diagnostic approach conducive to intelligent digital transformation—guiding scientific, standardized fault resolution while laying solid foundations for CNC equipment fault diagnosis and intelligent automation system design. This cultivates craftsman spirit and innovative thinking, integrates theory with practice, and prepares fundamental skills for future technological contributions to the nation.

Conclusion

This paper proposes gradual digital transformation in the training, assessment, and evaluation of CNC machine tool installation, adjustment, and maintenance technicians and senior technicians. Using an approach readily accepted by practitioners and amenable to digital implementation, this transformation aligns with vocational skills improvement initiatives. By prioritizing successful implementation, we can benefit trainees, practitioners, and the industry while minimizing transformation risks.

References

[1] Document Compilation (2022) Mechanical Industry Vocational Skills Appraisal Guidance Center. *Opinions on Implementing the Development Integration of Highly-Skilled Talents and Engineering Technical Talents in the Engineering Technology Field (Trial)* Guofa [2018] No. 11 [S].

[2] Document Compilation (2022) Mechanical Industry Vocational Skills Appraisal Guidance Center. *State Council' s Opinions on Promoting the Lifelong*

Vocational Skills Training System Renshebufa [2018] No. 74 [S].

[3] *National Vocational Education Reform Implementation Plan* (2019-2021) [S].

[4] Document Compilation (2022) Mechanical Industry Vocational Skills Appraisal Guidance Center. *Notice of the General Office of the State Council on Issuing the Vocational Skills Improvement Action Plan (2019-2021)* Guobanfa [2019] No. 24 [S].

[5] *Vocational Skills Improvement Action Plan (2019-2021)* [S].

[6] Chinese Mechanical Engineering Society. *China Mechanical Engineering Technology Roadmap* [M]. Beijing: China Science and Technology Press, 2016.11.

[7] Equipment and Maintenance Engineering Branch of Chinese Mechanical Engineering Society. *Equipment Management and Maintenance Roadmap* [M]. Beijing: China Science and Technology Press, 2016.11.

[8] China Engineering Education Accreditation Association. *Engineering Education Accreditation Work Guide* [M]. Secretariat of China Engineering Education Accreditation Association, 2017.11.

[9] Wu Xiaotao, Chen Guanling, Yang Meihua, Tang Guochun. "Implementation of Logic Control System Modeling" [J]. *Computer Engineering*, 2005, 31(21): 195-.

[10] China Engineering Education Accreditation Association. *Engineering Education Accreditation Work Guide* [M]. Secretariat of China Engineering Education Accreditation Association, 2017.11.

Note: Figure translations are in progress. See original paper for figures.