

BED OF NAILS TEST FIXTURE

BED OF NAILS TEST FIXTURE IS AN ESSENTIAL TOOL IN THE ELECTRONICS MANUFACTURING INDUSTRY, USED TO FACILITATE THE EFFICIENT AND RELIABLE TESTING OF PRINTED CIRCUIT BOARDS (PCBs). THIS TESTING MECHANISM EMPLOYS NUMEROUS SPRING-LOADED PINS, OR "NAILS," THAT MAKE CONTACT WITH SPECIFIC TEST POINTS ON A PCB TO VERIFY ELECTRICAL FUNCTIONALITY AND DETECT DEFECTS. THE BED OF NAILS TEST FIXTURE IS INTEGRAL IN QUALITY CONTROL PROCESSES, ENABLING MANUFACTURERS TO IDENTIFY ISSUES EARLY AND REDUCE COSTLY REWORK. THIS ARTICLE EXPLORES THE DESIGN, OPERATION, AND ADVANTAGES OF BED OF NAILS TEST FIXTURES, AS WELL AS THEIR APPLICATIONS AND BEST PRACTICES FOR IMPLEMENTATION. READERS WILL GAIN A COMPREHENSIVE UNDERSTANDING OF HOW THESE DEVICES ENHANCE TESTING ACCURACY AND STREAMLINE PRODUCTION WORKFLOWS.

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OVERVIEW OF BED OF NAILS TEST FIXTURE

THE BED OF NAILS TEST FIXTURE IS A WIDELY USED TESTING APPARATUS DESIGNED TO PERFORM IN-CIRCUIT TESTING (ICT) AND FUNCTIONAL TESTING OF PCBs. IT CONSISTS OF A PLATFORM EQUIPPED WITH NUMEROUS SPRING-LOADED TEST PROBES THAT PRECISELY ALIGN WITH THE PCB'S TEST POINTS. WHEN A PCB IS PLACED ON THE FIXTURE, THE PROBES MAKE SIMULTANEOUS CONTACT WITH THESE POINTS, ALLOWING COMPREHENSIVE ELECTRICAL MEASUREMENTS. THIS METHOD ENABLES RAPID AND AUTOMATED TESTING OF COMPLEX ELECTRONIC ASSEMBLIES, ENSURING THAT EACH COMPONENT IS CORRECTLY PLACED AND FUNCTIONING AS INTENDED.

PURPOSE AND IMPORTANCE

THE PRIMARY PURPOSE OF A BED OF NAILS TEST FIXTURE IS TO DETECT MANUFACTURING DEFECTS SUCH AS SHORTS, OPENS, MISSING COMPONENTS, INCORRECT POLARITY, AND SOLDERING ISSUES. BY PERFORMING THOROUGH ELECTRICAL CHECKS, IT REDUCES THE RISK OF FAULTY PRODUCTS REACHING THE MARKET. THIS TEST FIXTURE IS CRUCIAL FOR MAINTAINING PRODUCT QUALITY, IMPROVING YIELD RATES, AND MINIMIZING WARRANTY CLAIMS, MAKING IT AN INDISPENSABLE PART OF MODERN ELECTRONICS PRODUCTION LINES.

DESIGN AND COMPONENTS

THE DESIGN OF A BED OF NAILS TEST FIXTURE INVOLVES CAREFUL CONSIDERATION OF THE PCB LAYOUT, TEST POINT LOCATIONS, AND MECHANICAL CONSTRAINTS. EACH FIXTURE IS CUSTOM-BUILT TO MATCH THE SPECIFIC PCB IT WILL TEST, ENSURING ACCURATE ALIGNMENT AND RELIABLE CONTACT.

Key Components

- **Base Plate:** A sturdy platform that holds the entire fixture assembly and supports the PCB during testing.
- **Spring-Loaded Pins (Test Probes):** These conductive pins provide electrical contact with the PCB test pads. Their spring mechanism ensures consistent pressure and reliable connections.
- **Alignment Pins:** Used to position the PCB accurately on the fixture, preventing misalignment during testing.
- **Electrical Connectors:** Interface the test probes with the test equipment, facilitating signal transmission and measurement.
- **Pressure Plate or Cover:** Applies uniform pressure on the PCB to maintain contact between the pins and test points.

Customization and Materials

Materials used in bed of nails test fixtures are selected for durability, conductivity, and mechanical stability. Common materials include aluminum or steel for the base plate, and high-quality beryllium copper or stainless steel for the test pins. Customization involves optimizing pin placement density and probe length to accommodate diverse PCB designs and testing requirements.

Working Principle

The bed of nails test fixture operates by physically interfacing with a PCB's test points through an array of spring-loaded pins. Each pin corresponds to a specific node on the circuit, enabling simultaneous testing of multiple electrical parameters.

Test Execution Process

1. **PCB Placement:** The PCB is carefully positioned on the fixture using alignment pins to ensure accurate probe contact.
2. **Contact Establishment:** The pressure plate presses the PCB onto the spring-loaded pins, which compress to maintain firm electrical contact.
3. **Signal Transmission:** Electrical signals are sent through the probes to the PCB, allowing measurement of voltage, current, resistance, and continuity.
4. **Data Collection:** Test equipment analyzes the responses to detect faults such as shorts, opens, incorrect component values, or miswiring.
5. **Test Completion:** After testing, the PCB is released and either passes for assembly or is routed for repair if defects are found.

TYPES OF TESTS PERFORMED

BED OF NAILS TEST FIXTURES SUPPORT VARIOUS TEST TYPES INCLUDING:

- **IN-CIRCUIT TESTING (ICT):** VERIFIES INDIVIDUAL COMPONENTS AND CONNECTIONS WITHIN THE CIRCUIT.
- **FUNCTIONAL TESTING:** SIMULATES OPERATIONAL CONDITIONS TO ENSURE THE PCB PERFORMS ITS INTENDED FUNCTIONS.
- **BOUNDARY SCAN TESTING:** USES SPECIALIZED TEST ACCESS PORTS TO CHECK INTEGRATED CIRCUITS WITHOUT PHYSICAL PROBING.

APPLICATIONS IN ELECTRONICS MANUFACTURING

BED OF NAILS TEST FIXTURES ARE EXTENSIVELY USED IN MULTIPLE SECTORS OF ELECTRONICS MANUFACTURING. THEIR ABILITY TO PROVIDE RAPID AND COMPREHENSIVE TESTING MAKES THEM VITAL FOR HIGH-VOLUME PRODUCTION ENVIRONMENTS.

INDUSTRIES UTILIZING BED OF NAILS TEST FIXTURES

- **CONSUMER ELECTRONICS:** SMARTPHONES, TABLETS, AND HOUSEHOLD APPLIANCES REQUIRE STRINGENT PCB TESTING FOR RELIABILITY.
- **AUTOMOTIVE ELECTRONICS:** SAFETY-CRITICAL SYSTEMS LIKE AIRBAG CONTROLLERS AND ENGINE MANAGEMENT UNITS DEPEND ON RIGOROUS TESTING.
- **INDUSTRIAL EQUIPMENT:** CONTROL SYSTEMS AND INSTRUMENTATION BENEFIT FROM BED OF NAILS TESTING TO ENSURE OPERATIONAL INTEGRITY.
- **MEDICAL DEVICES:** HIGH STANDARDS FOR PATIENT SAFETY DEMAND THOROUGH PCB VERIFICATION IN MEDICAL ELECTRONICS.

VOLUME AND PRODUCTION CONSIDERATIONS

DUE TO THEIR SPEED AND ACCURACY, BED OF NAILS TEST FIXTURES ARE IDEAL FOR MASS PRODUCTION. THEY MINIMIZE TESTING TIME PER UNIT, SUPPORT AUTOMATION INTEGRATION, AND HELP MAINTAIN CONSISTENT QUALITY STANDARDS ACROSS LARGE PRODUCTION RUNS.

ADVANTAGES AND LIMITATIONS

UNDERSTANDING THE STRENGTHS AND WEAKNESSES OF BED OF NAILS TEST FIXTURES ENABLES MANUFACTURERS TO MAKE INFORMED DECISIONS ABOUT THEIR TESTING STRATEGIES.

ADVANTAGES

- **HIGH TEST COVERAGE:** SIMULTANEOUS PROBING OF MULTIPLE TEST POINTS ENSURES COMPREHENSIVE FAULT DETECTION.
- **FAST TESTING SPEED:** ENABLES RAPID THROUGHPUT SUITABLE FOR HIGH-VOLUME MANUFACTURING.

- **RELIABLE CONTACT:** SPRING-LOADED PINS MAINTAIN CONSISTENT PRESSURE, REDUCING FALSE FAILURES.
- **CUSTOMIZABILITY:** FIXTURES CAN BE TAILORED TO SPECIFIC PCB DESIGNS AND TEST REQUIREMENTS.
- **IMPROVED QUALITY ASSURANCE:** EARLY DETECTION OF DEFECTS REDUCES DOWNSTREAM FAILURES AND WARRANTY COSTS.

LIMITATIONS

- **HIGH INITIAL COST:** CUSTOM FIXTURES REQUIRE SIGNIFICANT UPFRONT INVESTMENT IN DESIGN AND FABRICATION.
- **MAINTENANCE REQUIREMENTS:** PINS CAN WEAR OUT OR BECOME MISALIGNED, NECESSITATING REGULAR UPKEEP.
- **LIMITED TO ACCESSIBLE TEST POINTS:** COMPLEX PCBs WITH HIDDEN OR DENSELY PACKED COMPONENTS MAY POSE CHALLENGES.
- **PHYSICAL STRESS ON PCB:** REPEATED MECHANICAL CONTACT CAN POTENTIALLY DAMAGE SENSITIVE BOARDS IF NOT MANAGED PROPERLY.

BEST PRACTICES FOR IMPLEMENTATION

OPTIMIZING THE USE OF BED OF NAILS TEST FIXTURES INVOLVES CAREFUL PLANNING, DESIGN, AND MAINTENANCE TO MAXIMIZE EFFICIENCY AND ACCURACY.

DESIGN CONSIDERATIONS

PROPER FIXTURE DESIGN SHOULD ACCOUNT FOR PCB LAYOUT COMPLEXITY, TEST POINT ACCESSIBILITY, AND PROBE PLACEMENT DENSITY. EARLY COLLABORATION BETWEEN TEST ENGINEERS AND PCB DESIGNERS CAN FACILITATE OPTIMAL TEST POINT ALLOCATION.

MAINTENANCE AND CALIBRATION

REGULAR INSPECTION AND REPLACEMENT OF WORN PINS ARE CRITICAL TO SUSTAINING TEST RELIABILITY. CALIBRATION OF TEST EQUIPMENT AND VERIFICATION OF FIXTURE ALIGNMENT HELP PREVENT FALSE NEGATIVES OR POSITIVES.

INTEGRATION WITH AUTOMATED TESTING SYSTEMS

INCORPORATING BED OF NAILS FIXTURES INTO AUTOMATED TEST LINES ENHANCES THROUGHPUT AND CONSISTENCY. INTEGRATION WITH SOFTWARE PLATFORMS ENABLES DATA LOGGING, FAULT ANALYSIS, AND TRACEABILITY.

FUTURE TRENDS AND INNOVATIONS

THE BED OF NAILS TEST FIXTURE CONTINUES TO EVOLVE WITH ADVANCES IN TECHNOLOGY AND MANUFACTURING DEMANDS. INNOVATIONS AIM TO IMPROVE FLEXIBILITY, REDUCE COSTS, AND ENHANCE TEST CAPABILITIES.

EMERGING TECHNOLOGIES

- **ADAPTIVE PROBING:** USE OF ROBOTIC ARMS OR ADJUSTABLE PINS FOR DYNAMIC TEST POINT ALIGNMENT.
- **MINIATURIZED PINS:** DEVELOPMENT OF SMALLER, MORE PRECISE PROBES FOR HIGH-DENSITY PCBs.
- **INTEGRATION WITH BOUNDARY SCAN:** COMBINING PHYSICAL PROBING WITH DIGITAL TEST TECHNIQUES FOR COMPREHENSIVE COVERAGE.
- **IMPROVED MATERIALS:** ADVANCES IN PIN COATINGS AND BASE MATERIALS TO INCREASE DURABILITY AND REDUCE WEAR.

IMPACT OF INDUSTRY 4.0

SMART MANUFACTURING TRENDS LEVERAGE DATA ANALYTICS AND IoT TO MONITOR FIXTURE PERFORMANCE IN REAL TIME, PREDICT MAINTENANCE NEEDS, AND OPTIMIZE TEST PROCESSES, FURTHER ENHANCING THE EFFICIENCY OF BED OF NAILS TEST FIXTURES IN PRODUCTION ENVIRONMENTS.

FREQUENTLY ASKED QUESTIONS

WHAT IS A BED OF NAILS TEST FIXTURE USED FOR?

A BED OF NAILS TEST FIXTURE IS USED IN ELECTRONICS MANUFACTURING TO TEST PRINTED CIRCUIT BOARDS (PCBs) BY MAKING SIMULTANEOUS CONTACT WITH MULTIPLE TEST POINTS TO CHECK FOR FUNCTIONALITY AND DEFECTS.

HOW DOES A BED OF NAILS TEST FIXTURE WORK?

IT WORKS BY USING NUMEROUS SPRING-LOADED PINS (POGO PINS) ARRANGED IN A PATTERN MATCHING THE PCB'S TEST POINTS, ALLOWING ELECTRICAL SIGNALS TO BE SENT AND RECEIVED FOR COMPREHENSIVE CIRCUIT TESTING.

WHAT ARE THE ADVANTAGES OF USING A BED OF NAILS TEST FIXTURE?

ADVANTAGES INCLUDE FAST AND RELIABLE TESTING OF COMPLEX PCBs, THE ABILITY TO TEST MULTIPLE POINTS SIMULTANEOUSLY, AND DETECTION OF MANUFACTURING DEFECTS EARLY IN THE PRODUCTION PROCESS.

WHAT MATERIALS ARE COMMONLY USED TO MAKE BED OF NAILS TEST FIXTURES?

COMMON MATERIALS INCLUDE ALUMINUM OR STEEL FOR THE FIXTURE BASE AND HIGH-QUALITY SPRING-LOADED PINS MADE OF MATERIALS LIKE STAINLESS STEEL OR GOLD-PLATED CONTACTS FOR DURABILITY AND RELIABLE CONDUCTIVITY.

CAN A BED OF NAILS TEST FIXTURE BE CUSTOMIZED FOR DIFFERENT PCBs?

YES, BED OF NAILS TEST FIXTURES ARE TYPICALLY CUSTOMIZED TO FIT THE SPECIFIC LAYOUT AND TEST POINTS OF EACH PCB DESIGN, ENSURING ACCURATE AND EFFICIENT TESTING.

WHAT ARE THE LIMITATIONS OF BED OF NAILS TEST FIXTURES?

LIMITATIONS INCLUDE HIGH INITIAL TOOLING COSTS, POTENTIAL MECHANICAL WEAR OF PINS OVER TIME, DIFFICULTY TESTING VERY SMALL OR DENSELY PACKED COMPONENTS, AND THE NEED FOR PRECISE FIXTURE ALIGNMENT.

HOW DOES A BED OF NAILS TEST FIXTURE COMPARE TO FLYING PROBE TESTERS?

BED OF NAILS FIXTURES PROVIDE FASTER TESTING BY CONTACTING ALL POINTS SIMULTANEOUSLY BUT REQUIRE CUSTOM TOOLING AND ARE COST-EFFECTIVE FOR HIGH VOLUMES. FLYING PROBE TESTERS ARE FLEXIBLE, REQUIRE NO CUSTOM FIXTURES, AND SUIT LOW-VOLUME OR PROTOTYPE TESTING BUT ARE SLOWER.

ADDITIONAL RESOURCES

1. *MASTERING BED OF NAILS TEST FIXTURES: PRINCIPLES AND PRACTICES*

THIS BOOK OFFERS A COMPREHENSIVE INTRODUCTION TO BED OF NAILS TEST FIXTURES, COVERING THE FUNDAMENTAL PRINCIPLES BEHIND THEIR DESIGN AND OPERATION. IT DELVES INTO THE SELECTION OF COMPONENTS, LAYOUT CONSIDERATIONS, AND THE ROLE OF TEST FIXTURES IN QUALITY ASSURANCE FOR ELECTRONIC ASSEMBLIES. READERS WILL GAIN PRACTICAL INSIGHTS INTO TROUBLESHOOTING AND OPTIMIZING TEST SETUPS FOR IMPROVED RELIABILITY AND EFFICIENCY.

2. *DESIGN AND FABRICATION OF BED OF NAILS TEST FIXTURES*

FOCUSED ON THE ENGINEERING AND MANUFACTURING ASPECTS, THIS TITLE GUIDES READERS THROUGH THE ENTIRE PROCESS OF CREATING A BED OF NAILS TEST FIXTURE. IT INCLUDES DETAILED INSTRUCTIONS ON MECHANICAL DESIGN, MATERIAL SELECTION, AND FABRICATION TECHNIQUES. THE BOOK ALSO ADDRESSES COMMON CHALLENGES FACED DURING ASSEMBLY AND OFFERS SOLUTIONS TO ENHANCE FIXTURE DURABILITY AND PERFORMANCE.

3. *ELECTRONICS TESTING WITH BED OF NAILS FIXTURES: A PRACTICAL GUIDE*

THIS PRACTICAL GUIDE IS TAILORED FOR TECHNICIANS AND ENGINEERS INVOLVED IN ELECTRONICS TESTING. IT EXPLAINS HOW BED OF NAILS FIXTURES ARE USED TO PERFORM IN-CIRCUIT AND FUNCTIONAL TESTING OF PRINTED CIRCUIT BOARDS (PCBs). THE AUTHOR SHARES TIPS FOR SETTING UP TESTS, INTERPRETING RESULTS, AND MAINTAINING FIXTURES TO MINIMIZE DOWNTIME AND ENSURE ACCURATE MEASUREMENTS.

4. *ADVANCED TECHNIQUES IN BED OF NAILS TESTING*

EXPLORING BEYOND THE BASICS, THIS BOOK PRESENTS ADVANCED METHODOLOGIES AND INNOVATIONS IN BED OF NAILS TEST FIXTURES. TOPICS INCLUDE AUTOMATED TEST SEQUENCES, INTEGRATION WITH SOFTWARE TOOLS, AND THE USE OF SENSORS TO ENHANCE TEST COVERAGE. IT IS SUITED FOR PROFESSIONALS SEEKING TO IMPLEMENT CUTTING-EDGE TESTING SOLUTIONS IN MANUFACTURING ENVIRONMENTS.

5. *TROUBLESHOOTING AND MAINTENANCE OF BED OF NAILS TEST FIXTURES*

A DEDICATED RESOURCE FOR MAINTAINING TEST FIXTURES, THIS BOOK COVERS COMMON FAULTS AND REPAIR STRATEGIES FOR BED OF NAILS SETUPS. IT EXPLAINS DIAGNOSTIC PROCEDURES TO IDENTIFY ISSUES SUCH AS CONTACT FAILURES, WEAR AND TEAR, AND ALIGNMENT PROBLEMS. PREVENTATIVE MAINTENANCE PRACTICES ARE ALSO OUTLINED TO EXTEND THE LIFE OF TEST FIXTURES AND ENSURE CONSISTENT TEST RESULTS.

6. *QUALITY CONTROL IN ELECTRONICS MANUFACTURING: THE ROLE OF BED OF NAILS TEST FIXTURES*

THIS BOOK EXAMINES THE CRITICAL ROLE THAT BED OF NAILS TEST FIXTURES PLAY IN QUALITY CONTROL PROCESSES WITHIN ELECTRONICS MANUFACTURING. IT DISCUSSES HOW THESE FIXTURES CONTRIBUTE TO DEFECT DETECTION, YIELD IMPROVEMENT, AND COMPLIANCE WITH INDUSTRY STANDARDS. CASE STUDIES ILLUSTRATE SUCCESSFUL IMPLEMENTATION AND THE IMPACT ON OVERALL PRODUCTION EFFICIENCY.

7. *AUTOMATION AND ROBOTICS IN BED OF NAILS TESTING*

FOCUSING ON THE INTEGRATION OF AUTOMATION, THIS BOOK EXPLORES HOW ROBOTICS AND AUTOMATED SYSTEMS ENHANCE THE FUNCTIONALITY OF BED OF NAILS TEST FIXTURES. IT COVERS ROBOTIC HANDLING, AUTOMATED TEST SEQUENCING, AND DATA COLLECTION TECHNIQUES. THE CONTENT IS IDEAL FOR ENGINEERS LOOKING TO MODERNIZE THEIR TESTING LINES AND REDUCE MANUAL INTERVENTION.

8. *COST-EFFECTIVE BED OF NAILS TEST FIXTURE SOLUTIONS*

THIS TITLE OFFERS STRATEGIES FOR DESIGNING AND DEPLOYING BED OF NAILS TEST FIXTURES ON A BUDGET WITHOUT COMPROMISING QUALITY. IT DISCUSSES COST-SAVING MATERIALS, MODULAR DESIGNS, AND EFFICIENT MANUFACTURING PROCESSES. READERS WILL LEARN HOW TO BALANCE PERFORMANCE REQUIREMENTS WITH FINANCIAL CONSTRAINTS IN VARIOUS PRODUCTION SCENARIOS.

9. *INNOVATIONS IN BED OF NAILS TEST FIXTURE TECHNOLOGY*

HIGHLIGHTING RECENT TECHNOLOGICAL ADVANCEMENTS, THIS BOOK REVIEWS NEW MATERIALS, DESIGN SOFTWARE, AND TESTING

METHODOLOGIES THAT ARE SHAPING THE FUTURE OF BED OF NAILS FIXTURES. IT EXPLORES TRENDS SUCH AS MINIATURIZATION, FLEXIBLE TEST FIXTURES, AND SMART DIAGNOSTICS. THE BOOK IS A VALUABLE RESOURCE FOR R&D PROFESSIONALS AND INDUSTRY INNOVATORS.

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boards (PCBs) in a practical manufacturing environment, by discussing printed circuit board faults and the test strategies implemented to detect these faults. This text emphasizes in-circuit testing as a prime test and diagnostic technique. Test strategies are described - implementing functional board testers, in-circuit board testers, in-circuit analyzers, and loaded board shorts testers. Also discussed are in-circuit tester's hardware, software, fix turing, and programming. Specific attention has been given to the in-circuit tester's capabilities and limitations, features and benefits, advantages and disadvantages. Chapter 5, as part of the total production testing process, discusses rework stations, network ing, and test area management. Chapter 8 is devoted to discussing the benefits derived by employing in-circuit testing in the service repair arena. This text concludes with chapters on vendor investiga tion and a financial justification. Additional emphasis is placed on having design engineering acquire an interest in manufacturability, testability, and the importance of consulting with manufacturing early in the design process. This book is designed for ease of reading and comprehension for all levels of interest: ATE students, fust-time ATE users, as well as those involved in test, manufacturing, quality control or assurance, production, engineering, and management.

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bed of nails test fixture: Multi-Chip Module Test Strategies Yervant Zorian, 2012-12-06 MCMs today consist of complex and dense VLSI devices mounted into packages that allow little physical access to internal nodes. The complexity and cost associated with their test and diagnosis are major obstacles to their use. Multi-Chip Module Test Strategies presents state-of-the-art test strategies for MCMs. This volume of original research is designed for engineers interested in practical implementations of MCM test solutions and for designers looking for leading edge test and design-for-testability solutions for their next designs. Multi-Chip Module Test Strategies consists of eight contributions by leading researchers. It is designed to provide a comprehensive and well-balanced coverage of the MCM test domain. Multi-Chip Module Test Strategies has also been published as a special issue of the Journal of Electronic Testing: Theory and Applications (JETTA, Volume 10, Numbers 1 and 2).

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bed of nails test fixture: *Automating Quality Systems* J.D. Tannock, 2012-12-06 Quality is a topical issue in manufacturing. Competitive quality performance still eludes many manufacturers in the traditional industrialized countries. A lack of quality competitiveness is one of the root causes of the relative industrial decline and consequent trade imbalances which plague some Western economies. Many explanations are advanced for poor quality performance. Inadequate levels of investment in advanced technology, together with insufficient education and training of the workforce, are perhaps the most prominent. Some believe these problems are caused by a lack of awareness and commitment from top management, while others point to differences between industrial cultures. The established remedy is known as Total Quality Management (TQM). TQM requires a corporate culture change, driven from the top, and involving every employee in a process of never-ending quality improvement aimed at internal as well as external customers. The

techniques deployed to achieve TQM include measures to improve motivation, training in problem-solving and statistical process control (SPC). Quality is, however, only one of the competitive pressures placed upon the manufacturer by the modern global economy. It is also imperative to remain economical and efficient, while increasing the flexibility and responsiveness of the design and manufacturing functions. Here the reduction or elimination of stock is of great importance, particularly as financial interest rates in the less successful manufacturing nations are frequently high. Product life cycles must become ever more compressed in response to the phenomenal design-to-manufacture performance of some Pacific rim economies.

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