ZIPPTORK
Bolting Technology
Torque Control 、Bolt Load Control

FCA
Fastening Capability Analyzer
Engineering White Paper

A Standardized Methodology for Characterizing Fastening Capability
Particularly valuable for Impact & Pulse Tools

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www.zipptork.com

Contents

From Fastening Fundamentals to Characterization, Applications, and FCA Platform Technology

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The Missing Engineering Method in Fastening Technology

Why Torque Measurement Alone Cannot Fully Characterize Fastening Capability

Traditional Engineering Practice

Traditional fastening evaluation typically measures:

- Tool Output Torque Measurement
- Residual Torque Verification
- Clamp Force / Preload Measurement
- Tool-to-Tool Comparison

OUTPUT TORQUE ≠ FASTENING CAPABILITY

Fastening Capability is determined by the interaction of the tool, fastener, joint, and operating conditions.

The Engineering Gap

Existing methods provide valuable measurements, but each describes only part of the fastening process.

They do not, by themselves, establish a systematic characterization of how a Defined Test Combination produces residual torque, clamp force, and fastening behavior.

Fastening Capability Characterization converts individual measurements into engineering knowledge under a Defined Test Combination.

Existing Engineering Methods Answer Different Questions

Each method provides valuable information—but no single measurement describes the complete fastening capability

Engineering Method	Tool Output Torque	Residual Torque	Clamp Force	Fastening Behavior	Capability Characterization
Torque Measurement	✓	—	—	—	—
Residual Torque Verification	—	✓	—	—	—
Clamp Force Measurement	—	—	✓	Partial	—
Fastening Capability Characterization	Input / Reference	✓	✓	✓	✓

FASTENING CAPABILITY CHARACTERIZATION

Integrates multiple measurements under a Defined Test Combination to characterize fastening behavior and capability.

Defined Test Combination + Clamp Force Measurement + Residual Torque Verification

↓

FASTENING CAPABILITY

↑

1. Torque Measurement
Measures what the tool delivers.
Output: Tool Output Torque

2. Residual Torque Verification
Measures what remains after tightening.
Output: Residual Torque

3. Clamp Force Measurement
Measures the resulting preload.
Output: Clamp Force / Bolt Preload

Measurement provides individual results. FCA integrates those results into Fastening Capability Characterization.

What Does It Mean to Characterize Fastening Capability?

Measurement Quantifies. Characterization Explains.

Measurement

Quantifies Individual Results

What does it tell us?

- Tool Output Torque
- Residual Torque
- Clamp Force / Preload

Produces:
Individual Measurement Data

Answers:
“What was measured?”

DATA → CORRELATION & ANALYSIS

↓

ENGINEERING KNOWLEDGE

Characterization

Explains Fastening Capability

Under a Defined Test Combination

- Relates measured results
- Identifies fastening behavior
- Establishes repeatability and correlation
- Defines applicability of the results

Produces:
Engineering knowledge

Answers:
“What does the measured behavior mean?”

Measurement provides the data.

Characterization explains what those data mean for Fastening Capability.

What Defines Fastening Capability?

Fastening Capability Is Determined by the Interaction of Four Governing Factors

Tool Side

Tool Characteristics

Determines how fastening energy is generated and delivered.

• Impact Wrench • Pulse Tool • Tool Capacity

• Drive / Impact Characteristics

Operating Conditions

Determines how the selected tool operates.

- Air Pressure / Supply Voltage
- Air Supply / Battery Condition
- Fastening Time
- Tool Setup / Connection Conditions

Fastening Capability

Characterized under a Defined Test Combination

Joint Characteristics

Determine how the joint responds to tightening.

•Joint Stiffness (Hard/Soft) •Material

• Contact • Surface Condition

Application Side

Fastener Characteristics

Determines how fastening input is converted into clamp force.

• Bolt • Nut • Washer • Thread Pitch• Thread Accuracy • Surface Condition • Lubrication

No single factor defines Fastening Capability—
It is determined by the interaction of all four factors under a Defined Test Combination.

Why Is a Defined Test Combination Essential?

Fastening Capability can only be meaningfully characterized when the governing factors are clearly defined.

A Defined Test Combination consists of a specific fastening tool, operating conditions, fastener combination, and joint characteristics.

DEFINED TEST COMBINATION

TOOL CHARACTERISTICS

Selected Tool • Tool Capacity • Drive / Impact Characteristics

＋

OPERATING CONDITIONS

Air Pressure / Supply Voltage • Air Supply / Battery Condition • Fastening Time • Tool Setup

＋

FASTENER CHARACTERISTICS

Bolt • Nut • Washer • Thread • Surface Condition • Lubrication

＋

JOINT CHARACTERISTICS

Joint Stiffness • Material • Contact / Surface Condition

WHY IT MATTERS

① REPEATABILITY

Creates a Reliable Characterization Baseline

The same defined combination provides a consistent reference for repeated characterization.

② COMPARABILITY

Enables Meaningful Comparison

Different tools, fasteners, joints, or operating conditions can be compared by varying one defined factor while holding the others constant.

③ APPLICABILITY

Supports Application-Specific Characterization

Characterization results apply only to the Defined Test Combination or to conditions demonstrated to be comparable.

Changing the combination may change the fastening capability.
Therefore, characterization must always be linked to its Defined Test Combination.

How Is Fastening Characterization Performed?

A Standardized Methodology Converts a Defined Test Combination into Characterized Fastening Capability.

① DEFINE OBJECTIVE

What engineering question needs to be answered?

↓

② ESTABLISH DEFINED TEST COMBINATION

Tool • Operating Conditions • Fastener • Joint

↓

③ PERFORM CHARACTERIZATION TESTS

Measure & Record Results Under the Defined Test Combination

Clamp Force • Residual Torque • Fastening Time • Operating Inputs

↓

④ CORRELATE & ANALYZE

Repeatability • Correlation • Behavior Trends • Applicability

↓

⑤ CHARACTERIZE FASTENING CAPABILITY

Application-Specific Engineering Knowledge

Characterization is not a single test result—it is a systematic description of fastening behavior established under a Defined Test Combination.

Different characterization objectives may require different test methods and parameters.

FCA Measurement Principle

From Direct Clamp Force Measurement to Residual Torque–Clamp Force Correlation

Measured Clamp Force serves as the reference for establishing an empirical relationship with verified residual torque under a Defined Test Combination.

① DEFINED TEST COMBINATION
Tool + Operating Conditions + Fastener + Joint

↓

② FASTENING TEST
Fastening with Impact Wrench / Pulse Tool

↓

③ DIRECT CLAMP FORCE MEASUREMENT
TTT Sensing Ring

Clamp Force vs. Time

↓

④ RESIDUAL TORQUE VERIFICATION
Measured After Fastening

↓

⑤ ESTABLISH CORRELATION
Measured Clamp Force ↔ Verified Residual Torque

↓

CHARACTERIZATION PARAMETERS

CORRELATION IS SPECIFIC TO THE DEFINED TEST COMBINATION

The established correlation characterizes fastening behavior—it is not a universal torque–clamp force conversion.

FCA converts directly measured clamp force and verified residual torque into characterization parameters that describe fastening behavior under the Defined Test Combination.

From Characterization Parameters to Fastening Capability

Characterization Parameters reveal how defined factors affect Fastening Capability.

① ESTABLISHED CHARACTERIZATION PARAMETERS

Clamp Force • Residual Torque • Correlation • Behavior Trends

↓

② DEFINE THE ENGINEERING QUESTION

Tool Capability • Required Fastening Time • Operating Conditions • Comparison

↓

③ VARY THE SELECTED FACTOR

Change one defined factor while holding the others constant

↓

④ OBSERVE FASTENING BEHAVIOR

Clamp Force vs. Time

Residual Torque

Behavior Trend

↓

⑤ CHARACTERIZE FASTENING CAPABILITY

Determine how the selected factor affects Fastening Capability.

EXAMPLE — FASTENING TIME

Same Tool + Same Fastener + Same Joint + Same Operating Conditions

↓

Change Fastening Time

↓

Observe Clamp Force vs. Time

↓

Verify Residual Torque

↓

Target Torque → Required Fastening Time

WHAT CAN BE STUDIED?

• Operating Pressure • Supply Condition

• Fastening Time • Tool Type

• Fastener • Joint Variable

For comparative characterization, vary one defined factor while holding the others constant.

Characterization Parameters turn measured fastening behavior into practical engineering decisions.

FCA — An Engineering Discovery Platform for Fastening Characterization

One Characterization Platform. Multiple Engineering Applications.

1. Tool Engineering
- Fastening capability characterization
- Design optimization
- Competitive benchmarking
- Consistency verification

2. Process Engineering
- Tool selection
- Required fastening time determination
- Operating-condition optimization
- Process validation

3. Controller Development
- Characterization parameters
- Off-Line training data
- Job Profile parameter establishment
- Control strategy development

Dynamic Clamp Force–Residual Torque Analysis

4. Fastener & Joint Engineering
- Fastener characterization
- Coating and lubrication studies
- Washer and joint comparison
- Residual Torque–Clamp Force analysis

5. Quality Assurance
- Incoming quality verification
- Production verification
- Maintenance / Service verification
- Digital reporting

6. Research & Education
- Impact / Pulse fastening studies
- Hard / Soft Joint studies
- Friction / Thread studies
- Engineering education & demonstration

MEASURE • CORRELATE • CHARACTERIZE • APPLY

These represent typical engineering applications—not the limits of the platform.

Characterization data transforms measured fastening behavior into practical engineering knowledge across the product and production lifecycle.

FCA for Controller Training

Using Fastening Characterization to Establish Controller Training Parameters Off-Line

TIME-BASED CHARACTERIZATION METHOD

① BEFORE PRODUCTION
Establish training parameters before line deployment

② REPLICATED CONDITIONS
Characterize the actual tool, fastener, joint, and operating conditions offline.

③ REDUCE TRIAL-AND-ERROR
Provide measured characterization data to establish the **Controller Job Profile.**

DEFINED FASTENING APPLICATION
Tool • Fastener • Joint • Target Torque • Operating Conditions
↓
OFF-LINE FCA CHARACTERIZATION
Replicate the Defined Fastening Application
↓
FASTENING TEST
Selected Tool at Defined Operating Conditions
↓
CLAMP FORCE vs. TIME
Direct Clamp Force Measurement
↓
RESIDUAL TORQUE VERIFICATION
Measured After Fastening
↓
CLAMP FORCE ↔ RESIDUAL TORQUE CORRELATION
↓
TARGET TORQUE → REQUIRED FASTENING TIME
↓
CONTROLLER TRAINING PARAMETERS
↓
JOB PROFILE

WHERE FCA FITS

ON-STATION
Actual Production Conditions
Direct / **SWF + ST** Assisted
vs
OFF-LINE
Replicated Production Conditions
Test Bench / **FCA**

FCA transforms off-line fastening characterization into practical Controller training parameters for production Job Profile establishment.

FCA for Fastening Engineering Validation

Turning fastening theory, design data, and published specifications into measurable engineering results.

① TOOL CHARACTERIZATION

Evaluate fastening capability across different torque-tool technologies.

Applicable to
• Impact • Pulse • Continuous-Drive
• Manual / Powered Torque Tools

② FASTENER DATA VERIFICATION

Verify published torque–clamp force data for different fastener specifications.

- Material
- Property / Strength Grade
- Surface Treatment
- Lubrication
- Bolt / Nut / Washer Combination

Published Torque / Clamp Force Data
↕
FCA-Measured Clamp Force + Verified Residual Torque

③ FRICTION & SURFACE STUDIES

Experimentally characterize how friction-related variables affect fastening behavior.

• Surface Treatment • Lubrication
• Thread Condition • Bearing Surface
• Surface Condition

For comparative characterization, vary one defined factor while holding the others constant.

④ ENGINEERING THEORY

VERIFICATION: Compare theoretical or calculated relationships with measured fastening behavior.

Theory / Calculation
↓
Defined Test Combination
↓
FCA Measurement
↓
Measured Clamp Force / Residual Torque / Behavior Trend

FCA Platform Capability:
Not Limited to Impact / Pulse Tools

DEFINED TEST COMBINATION
↓
FCA
↓
MEASURED FASTENING BEHAVIOR

FCA provides a practical experimental platform for verifying how tools, fasteners, friction, surfaces, and joint conditions affect Fastening Capability.

FCA for Assembly & Process Engineering

Using Fastening Characterization for Tool Selection, Process Planning, and Production Preparation

Tool Selection

Select the appropriate tool based on the characterized fastening capability—**not output torque alone**.

Candidate Tool A / B / C
↓
Same Defined Application Conditions
↓
Compare Fastening Capability
↓
SELECT TOOL

FASTENING FEASIBILITY

Determine whether the selected tool can achieve the Target Torque within the required fastening time.

Selected Tool + Defined Application
↓
FCA Characterization
↓
Is the Target Torque achievable within the required time?
↓
YES → Suitable
NO → Change Tool / Optimize Conditions / Extend Time

TOOL SELECTION → FEASIBILITY → PROCESS SIMULATION → PRODUCTION PREPARATION

Process Simulation

Replicate defined production conditions before deploying the line.

• Tool • Fastener • Joint • Operating Conditions
↓
FCA
↓
Clamp Force vs. Time
Residual Torque
Fastening Behavior
↓
PROCESS REFERENCE

Incoming Quality Verification

Verify purchased tools and critical fasteners against an established characterization reference.

Incoming Tool / Incoming Fastener
↓
Test Under the Defined Test Combination
↓
Compare with Established Reference
↓
ACCEPT / REVIEW

FCA provides characterized fastening capability data for objective tool selection, process planning, and production preparation.

FCA for Fastener & Joint Engineering

Characterizing how fastener and joint variables affect Clamp Force, Residual Torque, and Fastening Capability.

① FASTENER COMBINATION STUDIES

Characterize the effects of different fastener combinations under controlled conditions.

• Bolt • Nut • Washer • Thread • Grade • Material
• New / Reused Fasteners

↓

Clamp Force • Residual Torque • Fastening Behavior

② SURFACE & LUBRICATION STUDIES

Characterize how friction-related conditions affect fastening behavior.

• Surface Treatment • Lubrication • Thread Condition
• Bearing / Contact Surface

↓

Residual Torque–Clamp Force Behavior

Product Development • Quality Verification • Competitive Benchmarking • Technical Documentation

③ JOINT CHARACTERIZATION

Characterize how joint conditions influence fastening response.

• Hard / Soft Joint • Material • Surface Condition

↓

Clamp Force vs. Time
Residual Torque
Fastening Behavior

④ COMPARATIVE CHARACTERIZATION

Compare one defined variable while holding the other factors constant.

REFERENCE COMBINATION

↕

MODIFIED COMBINATION

↓

Compare Characterization Results
Clamp Force
Residual Torque
Behavior Trend

FCA makes the effects of fastener and joint variables measurable, comparable, and characterizable.

FCA System Architecture

An Integrated Platform for Measuring, Correlating, and Characterizing Fastening Behavior

FASTENING TOOL
Impact • Pulse • Continuous-Drive • Manual / Powered Torque Tools

↓

DEFINED TEST COMBINATION
Fastener • Joint • Operating Conditions

↓

FCA CORE MEASUREMENT HARDWARE
TTT + ST
Direct Clamp Force Measurement

↓

SIGNAL / DATA ACQUISITION
Real-Time Clamp Force Data

↓

APPLICATION SOFTWARE
Clamp Force vs. Time
Residual Torque Verification Data
Correlation & Analysis
Characterization Parameters

↓

ENGINEERING OUTPUT
Fastening Capability
Behavior Trends
Comparison Data
Characterization Report

EXPANDABLE MEASUREMENT INPUTS

Wireless Torque Transducer
Dynamic Tool Torque
STA / TTA
Residual Torque Verification
Other Sensors / Measurement Modules
Additional Fastening Variables

Measurement inputs can be expanded according to the engineering objective.

FCA integrates physical testing, measurement data, and engineering analysis into one Fastening Capability Characterization platform.

FCA Application Software & Characterization Data

Transforming Measured Fastening Data into Visual, Correlated, and Actionable Engineering Information

① REAL-TIME DATA ACQUISITION

Capture fastening behavior during the fastening cycle.

- Clamp Force
- Fastening Time
- Test Parameters

② FASTENING BEHAVIOR VISUALIZATION

Display how Clamp Force develops throughout the fastening cycle.

Clamp Force vs. Time Curve
Fastening Behavior Trends
Cycle-to-Cycle Comparison

③ CORRELATION & CHARACTERIZATION

Combine directly measured Clamp Force with verified Residual Torque.

↓

Clamp Force ↔ Residual Torque Correlation

↓

Characterization Parameters

④ ENGINEERING DATA OUTPUT

Convert characterization results into usable engineering information.

- Fastening Capability
- Behavior Trends
- Comparison Data
- Characterization Report

DATA ASSOCIATION

Defined Test Combination

Tool • Operating Conditions • Fastener • Joint

↓

Characterization Data

FCA Application Software connects measured fastening data with its Defined Test Combination to create meaningful Characterization Data.

TTT + ST — FCA Core Measurement Hardware

Direct Clamp Force Measurement for Fastening Capability Characterization

TTT — Torque Tension Tester

- Houses the Defined Fastener / Joint Combination
- Directly senses Clamp Force
- Supports interchangeable fastener configurations
- Replicates defined fastening conditions

➕

ST — Signal Transmitter

- Receives Clamp Force Sensor Signal
- Signal Conditioning / Processing
- Transfers Measurement Data to Application Software

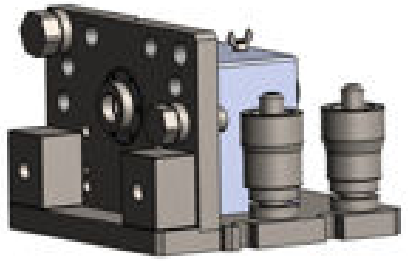
⬇

TTT-1214 ~ TTT-2027

M12 – M27 Configurations

TTT-3039

M30 – M39 Configurations



TTT

Clamp Force Sensing

↓

ST

Signal Processing

Transmission

↓

Laptop / Tablet

FCA Application Software

DIRECT CLAMP FORCE MEASUREMENT

Fastening Tool

↓

Defined Fastener + Joint

↓

TTT Bolt Load Sensing Assembly

↓

Direct Clamp Force Measurement

↓

Clamp Force vs. Time

➕

Verified Residual Torque

↓

Clamp Force ↔ Residual Torque Correlation

↓

Fastening Characterization Parameters

TTT + ST form the core physical measurement hardware of the expandable FCA platform.

TTT Core Hardware & Modular Fastener Configuration

Modular Configurations for Different Fastener Sizes and Application Requirements

TTT Modular Fastener Configuration

Example — B Platform

TTT-1418

M14 • M16 • M18

SW-18 Sensing Ring & Housing (# 5 & #4)

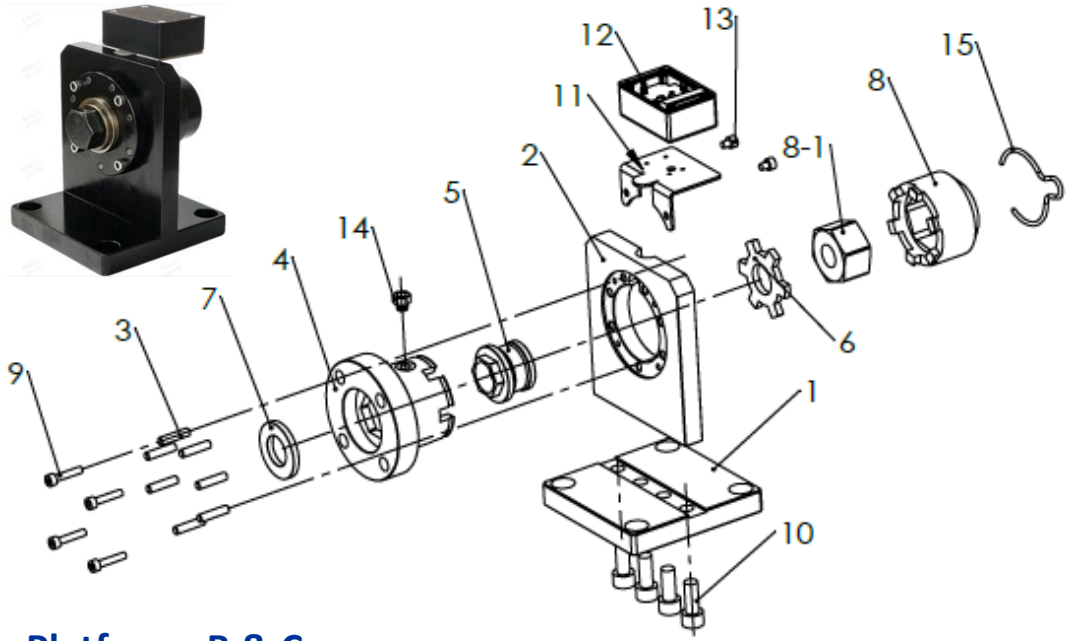
ID: 18.1 mm

M18 → Standard Configuration

M14 / M16 → Change #6, #7 & #8-1

Platform	Example Model	Selectable Bolt Configurations	Available Size Range
A	TTT-0510	M5/M6/M8/M10	M5–M10
B	TTT-1218	M12/M14/M16/M18	M12–M18
C	TTT-2024	M20/M22/M24	M20–M27
D	TTT-3036	M30/M33/M36	M30–M39

- Recommended: 3 consecutive bolt sizes; up to 4 sizes depending on configuration.
- Consecutive sizes are recommended for measurement consistency.
- Imperial/special configurations available upon request.



Platforms B & C —
Same Design, Different Sizes

MODULAR CONFIGURATION PRINCIPLE

Largest Bolt Size → Corresponding Sensing Ring & Housing

Smaller Bolt Sizes

↓

Change only #6 + #7 + #8-1 (Not Shown)

Same TTT Platform

Same Sensing Ring & Housing

One TTT platform can characterize multiple consecutive fastener sizes through modular interchangeable components.

TTT Measurement Range & Model Specifications

Measurement Capability Defined by the Selected Sensing Ring and Fastener Configuration

TTT Sensing & Characterization Capability

Platform	Sensing Ring	Bolt Size	Max. Clamp Force	Max. Fastening Torque for Characterization
A	SW-10	M10	45 kN	84 Nm
B	SW-18	M18	152 kN	500 Nm
C	SW-27	M27	369 kN	1,800 Nm
D	SW-39	M39	775 kN	5,400 Nm

TTT Model & Measurement Range

Item	A Platform		B Platform		C Platform		D Platform	
Configuration Model	TTT-0508	TTT-0610	TTT-1214	TTT-1218	TTT-2024	TTT-2027	TTT-3036	TTT-3039
Bolt Sizes	M5/M6/ M8	M6/M8/ M10	M12/M14	M12/M14/ M16/M18	M20/M22/ M24	M20/M22/ M24/M27	M30/M33/ M36	M30/M33/ M36/M39
Clamp Force Range (kN)	2-5	16-45	11-91	11-152	32-281	32-369	74-645	74-775
Applicable Fastening Torque Range (Nm)	2-7	18-84	24-235	24-500	115-1,220	115-1,800	395-4,150	395-5,400

Specifications may vary with the selected TTT configuration and sensing range. Custom configurations are available upon request.

TTT + ST Technical Specifications

Core Measurement, Signal Processing, Data Interface, and Software Specifications

① TTT MEASUREMENT SPECIFICATIONS

Item	Specification
Measured Parameter	Clamp Force
Measurement Method	Direct Dynamic Measurement
Sensing Element	**Sensing Ring**
Sensing Ring Accuracy	**±1% F.S.**
Measurement Range	**2–775 kN***
Measurement Output	Clamp Force vs. Time
Fastener Range	**M5–M39***
Configuration	Modular / Interchangeable

***Depending on the selected TTT configuration.**

https://chatgpt.com/s/t_6a82dbda22248191b36fc9995bc6cacc

② ST — SIGNAL & DATA INTERFACE

Item	Specification
Input	Sensing Ring Signal
Function	Signal Conditioning / Processing
Data Output	Real-Time Clamp Force Data
Wireless Transmission	**Bluetooth / RF**
USB Interface	**USB Type-C**
USB Type-C Function	Charging / Firmware Update
Battery	650 mAh Li-Polymer Rechargeable Battery
Display / Analysis	Laptop / Tablet
Software	FCA Application Software

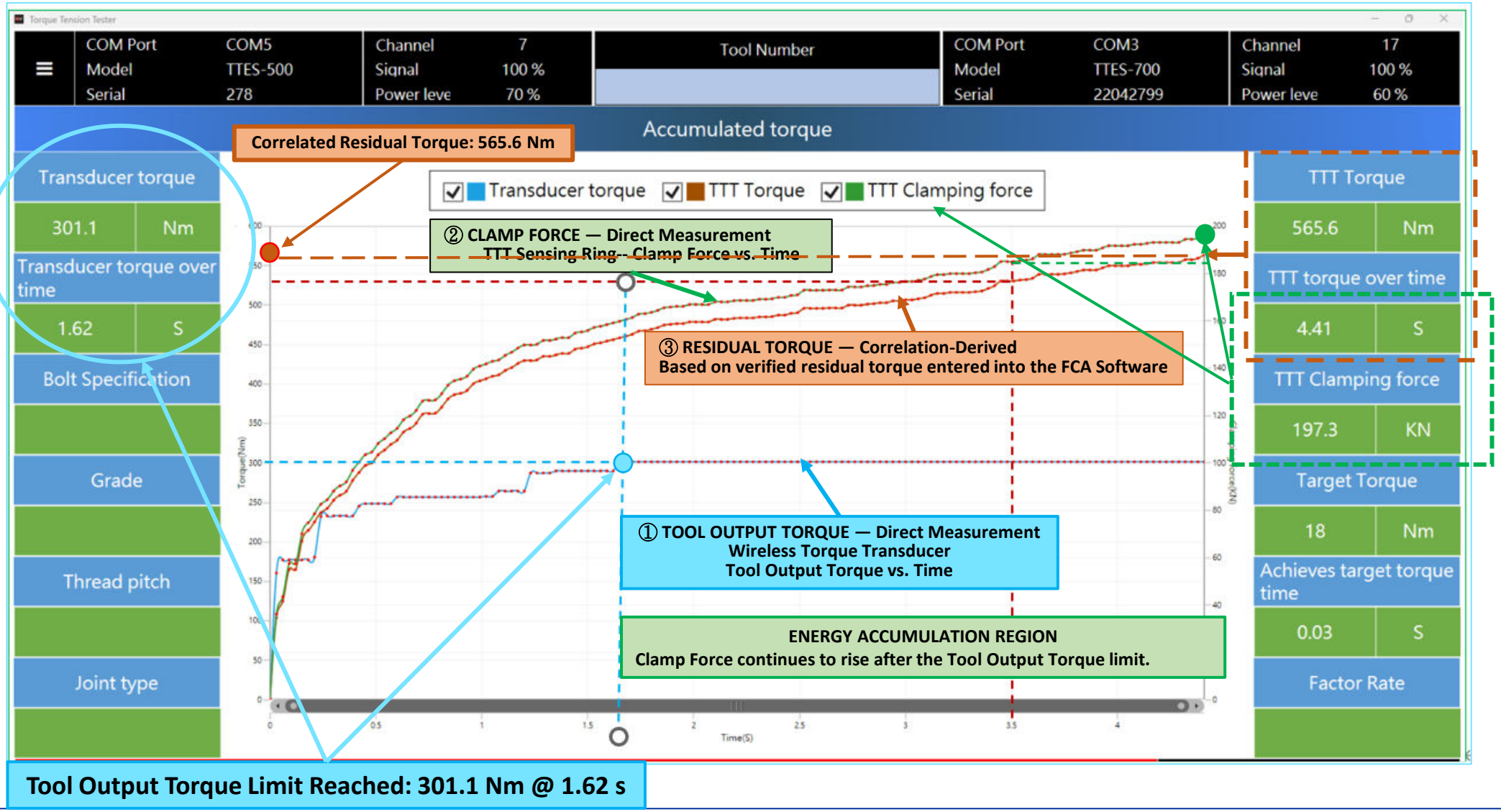
③ FCA CHARACTERIZATION DATA

Clamp Force Data
Directly Measured by **TTT**
+
Residual Torque Data
User-Verified / Entered into **FCA Software**
↓
Correlation & Characterization

Characterization results are specific to the Defined Test Combination and the verified residual torque data.

Dynamic Fastening Behavior Characterization

Visualizing Tool Output Torque, Clamp Force, and Residual Torque Throughout the Fastening Cycle



Tool Output Torque Limit Reached: 301.1 Nm @ 1.62 s

FCA reveals what torque measurement alone cannot show—how Clamp Force and correlated Residual Torque continue to develop after the tool reaches its output torque limit.

Sensing Ring Calibration & Measurement Verification

Verifying Direct Clamp Force Measurement Against a Reference Force Standard

CALIBRATION / VERIFICATION PROCESS

① REFERENCE FORCE STANDARD

Apply a known reference load

↓

② SENSING RING

Measure the applied Clamp Force

↓

③ ST SIGNAL PROCESSING

Acquire and process the sensing signal

↓

④ COMPARE

Reference Force ↔ Measured Clamp Force

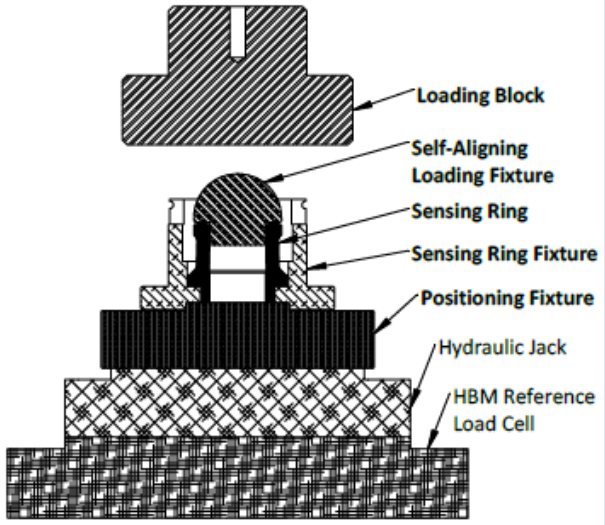
↓

⑤ CALIBRATE / VERIFY

Confirm measurement performance

Known Force → Sensing Ring → Compare

Sensing Ring Calibration & Verification Test Setup



WHAT IS VERIFIED?

ACCURACY

Sensing Ring Accuracy

±1% F.S.

Applies to direct Clamp Force measurement.

LINEARITY

Reference Force vs. Measured Clamp Force

Verify proportional response across the calibrated measurement range.

REPEATABILITY

Repeated Measurements at the Same Reference Load

Verify measurement consistency under identical test conditions.

Sensing Ring calibration verifies direct Clamp Force measurement only. It does not define the accuracy of FCA Residual Torque–Clamp Force Characterization.

Why FCA Matters for Fastening Engineering

From Individual Measurements to a Complete Understanding of Fastening Capability

INDIVIDUAL MEASUREMENTS

Tool Output Torque
What the tool delivers

Residual Torque
What remains after fastening

Clamp Force
The resulting preload

Fastening Time / Conditions
How the fastening was performed

↓

VALUABLE — BUT INDIVIDUAL RESULTS

FCA CHARACTERIZATION

DEFINED TEST COMBINATION
Tool
Fastener
Joint
Operating Conditions

↓

MEASURE

↓

CORRELATE

↓

CHARACTERIZE

FASTENING CAPABILITY

ENGINEERING KNOWLEDGE

Tool Capability

Fastening Behavior

Required Fastening Time

Fastener / Joint Effects

Process Feasibility

Controller Training Parameters

Comparison / Verification

Today
TTT + ST
Wireless Torque Transducer
STA / TTA
Controller
FCA Software

EXPANDABLE PLATFORM

Future Expansion
Additional Sensors
Additional Fastening Variables
Database / Cloud
IIoT / MES Integration
AI-Assisted Analysis

FCA does not replace torque or clamp-force measurement—it integrates them into a systematic engineering methodology for understanding Fastening Capability, particularly for impact wrenches and pulse tools.

FCA — From Measurement to Fastening Capability

A Standardized Engineering Methodology for Understanding, Characterizing, and Applying Fastening Behavior

① FASTENING CAPABILITY IS MORE THAN TORQUE

Tool Output Torque alone does not define the final fastening result.

Clamp Force, Residual Torque, fastening behavior, and operating conditions must be considered together.

② CHARACTERIZATION REQUIRES DEFINED CONDITIONS

Fastening Capability must be characterized under a Defined Test Combination.

Tool • Fastener • Joint • Operating Conditions

③ FCA CONNECTS MEASUREMENT WITH ENGINEERING KNOWLEDGE

Measure → Correlate → Characterize → Apply

FCA transforms individual measurement data into application-specific engineering knowledge.

④ FCA REVEALS DYNAMIC FASTENING BEHAVIOR

FCA reveals how Clamp Force and correlated Residual Torque develop throughout the fastening cycle.

Particularly valuable for impact and pulse tools, where Clamp Force can continue to develop after the tool reaches its output torque limit.

⑤ FCA IS AN EXPANDABLE ENGINEERING PLATFORM

Core Measurement Hardware + Expandable Inputs + Application Software

TTT + ST • Wireless Torque Transducer • STA / TTA • Controllers • Additional Measurement Modules

FCA transforms fastening from isolated measurement into systematic engineering knowledge—providing a practical foundation for better tools, fasteners, processes, and fastening control.