Pekos Clamping System: Engineering Analysis

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Engineering Analysis Report

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Abstract—This analysis resolved critical operational inconsistencies in the Pekos clamping system, improving force consistency by up to 350% (CI from 0.2 to 0.9) on affected stations. By identifying a fundamental gain margin issue exacerbated by mechanical differences, a data-driven optimization involving revised force parameters and control logic restored reliable operation across all units. Investigation revealed that Station 1's naturally higher mechanical resistance provided inherent damping, while Stations 2 and 3 operated with insufficient gain margin at lower forces. The implementation of a three-button control system and operation at higher forces (3-4 tonnes, approximately 30-40 kN) dramatically reduced force variation dramatically from 11.5 kN down to 1.5-3.0 kN, ensuring consistent clamping performance critical for quality assurance and certification requirements. This investigation provides a repeatable methodology for diagnosing complex system behaviors and addresses known challenges in internal documentation and knowledge capture.

I. Executive Summary

This engineering analysis addresses critical operational inconsistencies in the Pekos valve testing system (VCBT150-SA), where three identical clamping stations exhibited dramatically different performance characteristics. The investigation revealed:

- Measurable Performance Improvement: Force consistency improved by up to 350% (CI from 0.21 to 0.95) on affected stations, reducing force variation from 11.5kN to 1.5-3kN and ensuring reliable quality assurance testing.
- Root Cause Identification: A fundamental design-application mismatch occurred when the system, originally designed for inner/radial seal testing with minimal clamping force, was repurposed for flanged valves requiring significantly higher forces, with the same approach carried forward to the new machine.
- Critical Mechanical Insight: Station 1's naturally higher mechanical resistance provided inherent damping that maintained stability, while Stations 2 and 3 lacked this damping effect, creating a narrow detection window where $T_{start} \approx T_{clamp}$.
- Bi-Modal Stability Pattern: Testing revealed stable regions at both low (1.1-1.3 tonnes) and high (3-4 tonnes) forces, separated by an unstable transition zone that explained the inconsistent performance.
- Counterintuitive Solution: Operating at higher forces (3-4 tonnes, approx. 30-40 kN, rather than the original 2-tonne, approx. 20 kN constraint) dramatically improved system stability by moving operation away from a critical transition threshold.
- Practical Implementation: A three-button control system that separates positioning and clamping functions, combined with optimized force parameters, transformed inconsistent operation into reliable performance across all stations.
- Long-Term Value: The reduced parameter sensitivity ensures longer-term reliability with fewer service interventions, while providing a model for future troubleshooting of similar systems.

This case illustrates the practical realities of industrial problem-solving, where time and resource constraints often necessitate optimization within existing parameters rather than comprehensive redesign. While the data-driven approach ultimately yielded a functional solution, the experience highlights the importance of identifying and addressing root causes during initial system design to avoid cascading modifications later.

II. Introduction and Problem Statement

The Pekos valve testing system (model VCBT150-SA, order number 30196-24) is a semi-automatic test bench designed for body and bi-directional seat testing of ball valves. According to its design specifications, "During clamping and testing there will be no linear force on the valve body. The use of these adapters prevents 'squeezing' and deformation of the valve bodies. It is an ideal solution for clamping and testing all split-body valves with clean machined faces on the bore connections."

II-A. Historical Context and Modification History

The current system is mechanically similar to a previously deployed machine (order number 8724-13) that functioned properly until the customer began testing flanged valves, an application outside the original design parameters. Flanged valves require greater clamping force than the inner/radial seals the machine was designed to test. This led to a series of modifications:

1) Initial modification: Customer increased motor power/torque to achieve greater clamping force
2) Subsequent issue: Clamping stations began to stick, requiring manual release
3) Attempted solution: Installation of larger motors (upgrading from 0.75kW VL2 80 to 2.2kW G26-100L4, nearly tripling power output)

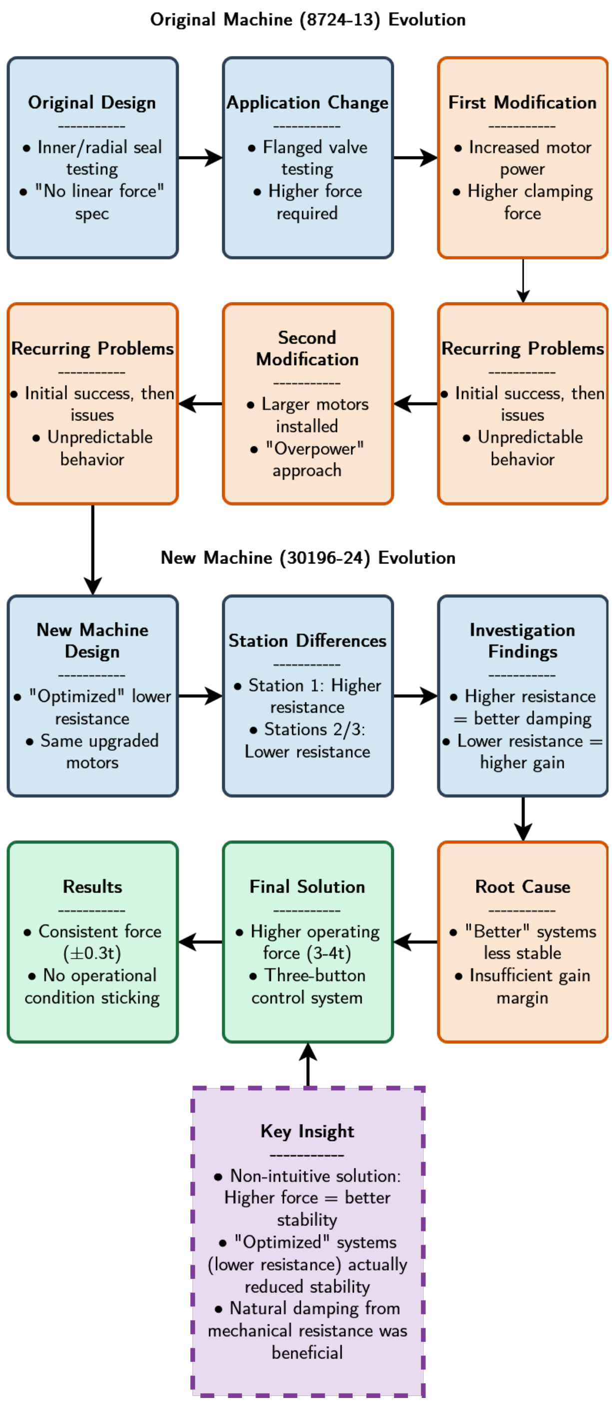

Fig. 1. Diagram contrasting the historical modification cycle of the original machine (8724-13, top) with the analytical investigation and solution development process for the new machine (30196-24, bottom), leading to the final three-button control approach with optimized force parameters.

4) Recurring problem: After initial success, sticking issues returned

II-B. Current System Status

The new machine (30196-24) was designed with:

1) More optimized system resulting in less resistance in clamping stations
2) Same "upgraded" motors used in the modified older machine
3) Similar operational issues discovered after targeted testing

This analysis documents the investigation into these issues, identifies the fundamental control system problems causing the inconsistencies, and details the optimization approach that successfully resolved them.

- Station 1 exhibited relatively consistent clamping behavior
- Station 2 and Station 3 showed extreme force variations under seemingly identical operating conditions
- Initial measurements revealed Station 1 had significantly higher mechanical resistance than the other stations, a difference that would prove critical to understanding the system behavior

III. Design Intent vs. Application Requirements

III-A. Original Design Parameters

- System designed for inner/radial seal testing requiring minimal clamping force
- Design specification explicitly states "no linear force on the valve body" to prevent deformation
- Clamping force specifications listed as "not applicable" in technical documentation

III-B. Application Change Impact

- Customer's transition to testing flanged valves created fundamentally different force requirements
- Flanged seals require significantly higher clamping force to achieve proper sealing
- This application change initiated a cascade of modifications that compromised system stability

IV. Fundamental Control System Concepts

Before presenting measurement data, it's important to establish key control system concepts relevant to this analysis:

IV-A. System Gain and Damping

The clamping system operates as a feedback control system where motor current/torque responds to resistance encountered during clamping. Two critical factors affect stability:

- System Gain: How responsive the system is to input changes. Higher gain means greater force change for the same input change.
- System Damping: The system's ability to absorb energy and stabilize after disturbances. Higher damping reduces oscillations and improves stability.

IV-B. Gain Margin Concept

Gain margin represents the buffer between normal operation and system instability. Insufficient gain margin causes:

- High sensitivity to small parameter changes
- Inconsistent response to similar inputs
- Potentially unstable operation

The investigation revealed that following motor upgrades, Station 2 and Station 3 were operating with insufficient gain margin at lower clamping forces, while Station 1's higher mechanical resistance provided natural damping that maintained adequate stability.

V. Investigation Timeline

V-A. Initial Conditions (Pre-Analysis)

- All three stations equipped with upgraded motors to address sticking issues
- Two-button control system (up/down)
- Target clamping force: 2 tonnes maximum
- Sticking issue discovered in Station 2 and Station 3 whilst testing a customer valve for the first time

V-B. Initial Analysis Phase

- Comparative measurements taken across all three stations
- Force variations documented
- Mechanical differences identified
- All testing conducted under original 2-tonne constraint

Note: All measurements and analysis in Sections VI, VII, and VIII were conducted under the original 2-tonne force constraint, prior to implementing the higher force solution.

V-C. Solution Development Phase

- Control system iterations tested
- Force targets reconsidered
- Final approach implemented with higher force targets (3-4 tonnes)

V-D. Validation Phase

- Performance metrics established
- Before/after comparisons conducted
- Stability verified across all stations

VI. Measurement Methodology

VI-A. Mechanical Resistance Measurements

Resistance measurements were conducted to identify mechanical differences between stations. Measurements included both spindle resistance and motor resistance under standardized conditions.

- Motor resistance testing: Motors were detached from the spindle gear assembly and tested in free-running condition to isolate their mechanical characteristics. Multiple measurements were taken for each motor to establish baseline resistance values independent of the spindle system. The percentage differences shown in Table I represent relative differences in motor resistance.
- Spindle resistance testing: Spindle resistance differences (Table I) were quantified by calculating the absolute difference in the average Motor Torque (%) observed during constant-speed positioning phases captured in data logs. This measurement reflects the additional torque required to maintain consistent movement throughout the spindle travel range. Point-force measurements were also taken at specific positions (top, middle, and bottom) using a calibrated load cell with a 715mm lever attached to the top nut of each spindle to provide complementary static resistance data.

TABLE I
Comparative Resistance Analysis Across Stations

Station Comparison	Resistance Difference	
	Spindle (Torque % pts)*	Motor (%)
Station 2 vs 3†	0.39	0.96
Station 1 vs 2	6.94	5.25
Station 1 vs 3†	6.55	6.21

* Spindle resistance difference calculated as the absolute difference in average Motor Torque (%) required during constant-speed positioning.

† Measurements were completed prior to a final minor gear mesh adjustment on Station 3 to address tightness. This adjustment likely reduced Station 3's final operational resistance relative to Station 2, potentially explaining the wider variability band observed for Station 3 in Figure 3.

VI-B. Force Application Measurements

Force measurements were conducted to characterize each station's performance under the original 2-tonne constraint. Key findings showed that Station 1 maintained consistent force application with minor localized variations, while Stations 2 and 3 exhibited similar behavior to each other but differed significantly from Station 1.

VI-C. Control System Response Characteristics

Torque profiles were measured to characterize the control system response during operation. A critical operational constraint was identified: $T_{start} \approx T_{clamp}$, meaning the torque required to initiate movement from standstill was very close to the torque required during actual clamping.

This torque profile analysis revealed why minor variations in mechanical resistance had outsized effects on system performance. With $T_{start} \approx T_{clamp}$, the system had minimal margin to distinguish between normal startup torque and actual clamping events. This created a fun-

Fig. 2. Torque and Speed vs. Time during a typical clamping operation. Top: Optimized process response (time axis normalized). Bottom: Original process response. Solid lines represent motor torque (%, left axis); dashed lines represent motor speed (rpm, right axis). Blue/Green lines denote the optimized process; Orange/Purple lines denote the original process. Note the significantly shorter ramp-up time in the optimized process and the proximity of initial start torque (T_{start}) to clamping torque (T_{clamp}) in the original process. The time axis for the optimized process (top) is normalized for duration comparison by removing 20.4s of constant-speed travel, resulting in a discontinuity.

damental control challenge that was exacerbated by the upgraded motors, which increased system gain without corresponding increases in damping.

VI-D. Data Collection and Analysis Approach

Each station underwent extensive testing across various parameter settings, with multiple measurement cycles per configuration to ensure reliability:

- Iterative testing: Multiple test cycles were conducted for each configuration to ensure repeatability and establish confidence intervals
- Parameter sensitivity: Control parameters were systematically varied to characterize response curves and identify stability thresholds
- Comparative analysis: Direct comparison between stations under identical control parameters isolated mechanical differences
- Statistical validation: Data underwent systematic processing with outlier detection and trend analysis to ensure measurement validity

VII. Root Cause Analysis

The fundamental issues identified can be traced to a series of reactive modifications that failed to address the core design-application mismatch:

VII-A. Insufficient Gain Margin

- Original system designed with appropriate gain margin for inner/radial seal testing
- Motor upgrades on the previous machine (8724-13) were implemented to address flanged valve testing issues, and these same oversized motors were then standardized for the new machine (30196-24) without reassessing their appropriateness (from 0.75kW VL2 80 to 2.2kW G26-100L4 - a dramatic increase in torque capability)
- This created a critically narrow detection window $T_{start} \approx T_{clamp}$
- Small variations in friction or other factors produced large variations in clamping force

The fundamental issue was that the upgraded motors created a system with excessive gain but insufficient damping. The torque required to initiate movement (T_{start}) became nearly identical to the torque needed for clamping (T_{clamp}), eliminating the detection margin needed for stable operation. This made the system hypersensitive to minor variations in mechanical conditions, where small changes in friction or other parameters would cause the system to either undershoot or overshoot the target clamping force significantly.

VII-B. System Damping Differences

- Station 1's significantly higher combined mechanical resistance created natural damping
- This damping provided greater stability and reduced parameter sensitivity
- Station 2 and Station 3 lacked this natural damping effect, resulting in unstable operation
- The optimized design of the new machine (30196-24) with reduced resistance exacerbated this issue

This difference in mechanical resistance is similar to the contrast between luxury vehicle suspension and race car suspension systems. Station 1's higher resistance (combining both the higher spindle resistance and motor resistance shown in Table I) functioned like a luxury car's soft, heavily damped suspension that absorbs road irregularities and maintains a smooth ride despite varying conditions. In contrast, Station 2 and Station 3 operated more like race cars with stiff, minimally damped suspensions - optimized for performance under ideal conditions but hypersensitive to small variations, where even minor irregularities cause significant disturbances to vehicle stability and control.

VIII. Consolidated Measurement Results

VIII-A. Mechanical Characteristics Comparison

The resistance analysis revealed three primary patterns:

- Consistent elevation in Station 1: Maintains significantly higher combined mechanical resistance compared to Stations 2-3
- Inter-station consistency: Station 2 and Station 3 show minimal variance (mean difference = 0.68%, σ = 0.29%)
- Systematic discrepancy: The mechanical resistance differential persists across all measurement cycles

VIII-B. Force Application Characteristics

Key force measurement insights:

- Station 1 variability: Exhibits σ=12.8N variance vs. $\sigma \leq$1.5N in other stations
  - Note: This variance occurs only in a small localized portion of the spindle's rotation
  - Despite this localized anomaly, Station 1 maintained superior overall force consistency
- Minor positional effects: Slight vertical gradient in force requirements (42.3N$\rightarrow$45.0N, 6
- Measurement stability: Stations 2-3 maintain <2N difference across positions, confirming their mechanical similarity despite their dramatically different performance characteristics.

VIII-C. Force Consistency Range (Before Optimization)

At the original 2-tonne target range, the difference in force consistency was stark:

- Station 1 (Higher Resistance): Maintained a relatively tight 1.9 kN range (11.2 - 13.1 kN).
- Station 2 (Lower Resistance): Exhibited extreme variability with a 11.3 kN range (8.7 - 20 kN).
- Station 3 (Lower Resistance): Similarly inconsistent with a 11.4 kN range (8.6 - 20 kN).

This dramatic ∼6x difference in force application range between Station 1 and Stations 2/3, despite similar torque settings, clearly highlighted the fundamental system stability issue linked to mechanical damping.

IX. Solution Development

IX-A. Control System Evolution

The clamping system control approach evolved through several iterations as shown in Figure 1 presented earlier:

1) Initial Iterations

Early attempts to resolve the issues included:

- Adding a 12-second delay before transitioning to fast mode (impractical for operators)
- Implementing a two-action button system (improved but still inconsistent, with operators struggling to distinguish modes due to poor tactile feedback)

2) Final Solution (Two-Part Change)

1) Control System Change: Three-button system
   - Original up/down buttons: Used only for quick spindle positioning
   - New dedicated third button: Used exclusively for clamping operations
2) Critical Parameter Change:
   - Acceptable clamping force range increased from 2 tonnes to 3-4 tonnes
   - This adjustment fundamentally changed the system's operational characteristics and stability
3) $T_{start} \approx T_{clamp}$ Workaround:
   - PLC configured to allow clamping only after 1s passed after movement initiation
   - Resulted in ignoring the large T_{start} spike, enabled to move spindle rapidly from standstill
4) Inverter Profile Optimization:
   - Changed from "coast to stop" to "ramp to stop" for controlled deceleration
   - Increased deceleration time from 0.1s to 0.5s for smoother operation
   - Maintained standard 5s acceleration ramp rate
   - These adjustments eliminated initial movement hesitation in Stations 2 and 3

IX-B. Force-Stability Relationship

The relationship between applied force and system stability follows a non-linear curve. Key relationships identified:

1) Mechanical Resistance and Damping Effect:
   - Station 1's substantially higher combined mechanical resistance provides enhanced damping

- characteristics compared to Station 2 and Station 3
- Analysis of torque response curves during clamping operations revealed more stable behavior in Station 1, consistent with improved damping properties
- This damping effect directly correlates with the significantly better force consistency observed in Station 1

2) Force Level and System Stability:
   - Operating at higher forces (3-4 tonnes) moves the system away from the critical transition threshold
   - This creates an effective "artificial damping" effect in Station 2 and Station 3, improving their stability characteristics
   - Force consistency measurements confirm this effect: Station 2's consistency index improved from 0.21 to 0.95, a 350% improvement
3) Operating Region Linearity:
   - At lower forces (≤ 2 tonnes), small variations in input parameters produced highly non-linear responses
   - At higher forces (3-4 tonnes), the system response became more predictable and consistent, suggesting operation in a more linear region of the system's response curve

IX-C. Bi-Modal Stability Pattern

Detailed testing revealed a critical bi-modal stability pattern across all stations, which is clearly visualized in Figure 3:

1) Low-Force Stable Region (1.1-1.3 tonnes):
   - Station 1 exhibited predictable, stable operation in this region due to its higher mechanical resistance, shown by the narrower blue shaded band in Figure 3
   - Extended button press causes gradual force increase after 10-20+ seconds
   - In contrast, Station 2 and Station 3 were largely unstable at these lower force levels, often exhibiting unpredictable jumps or failing to consistently reach target force until significantly higher scaling parameters were applied
2) Transition Zone (1.5-2.5 tonnes):
   - Highly unstable region with unpredictable force application, visible in Figure 3 as the rapidly widening shaded bands for Station 2 and Station 3 as they approach their respective transition points
   - Button hold time required for transition decreased as scaling parameters increased
   - Station 2 and Station 3 exhibited this transition at lower scaling values (92% and 75% respectively, marked by vertical dotted lines in Figure 3) compared to Station 1 (125%)
3) High-Force Stable Region (3-4 tonnes):
   - Immediate stabilization at consistent force levels, shown in Figure 3 where all three curves flatten and their variability bands narrow significantly
   - Extended button press produced no further force increase
   - All stations exhibited similar stability characteristics in this region, as evidenced by the similar width of all three shaded bands at higher force values
   - Testing confirmed stability well beyond 4 tonnes, however, an operational range of 3-4 tonnes was selected for the final solution as it provided sufficient clamping force while ensuring all stations operated comfortably within their high-force stable equilibrium

This bi-modal pattern explains why operating at higher forces produced more consistent results. The system naturally seeks equilibrium in either the low or high stable regions, with the transition zone representing an inherently unstable operating point. This behavior is analogous to a water faucet that operates smoothly at either very low flow (drip mode) or higher flow (steady stream), but experiences an unstable "splashing phase" at intermediate settings where small adjustments cause unpredictable water patterns.

As clearly demonstrated in Figure 3, the significantly higher mechanical resistance in Station 1 shifted its transition point to higher scaling values (125% vs. 92% for Station 2 and 75% for Station 3), providing critical insight into the relationship between mechanical characteristics and control system stability. The figure's shaded variability bands visually confirm this pattern, showing dramatically increased force variation (wider bands) for Station 2 and, slightly more pronouncedly for Station 3 (likely due to a final pre-shipment gear mesh adjustment), in the transition zone, while Station 1 maintains relatively consistent performance until reaching its own higher transition point.

IX-D. Performance Metrics and Validation

To quantify system improvements, a Consistency Index (CI) was developed:

$$\mathrm{CI} = 1 - \frac{\text{Force Range}}{\text{Regular Force}} \quad \text{where } 0 \leq \mathrm{CI} \leq 1 \tag{1}$$

This index provides a normalized measure of force consistency, where:

- CI = 1 represents perfect consistency (zero variation)
- CI = 0 represents complete inconsistency (variation equal to the target force)

This metric was selected because it:

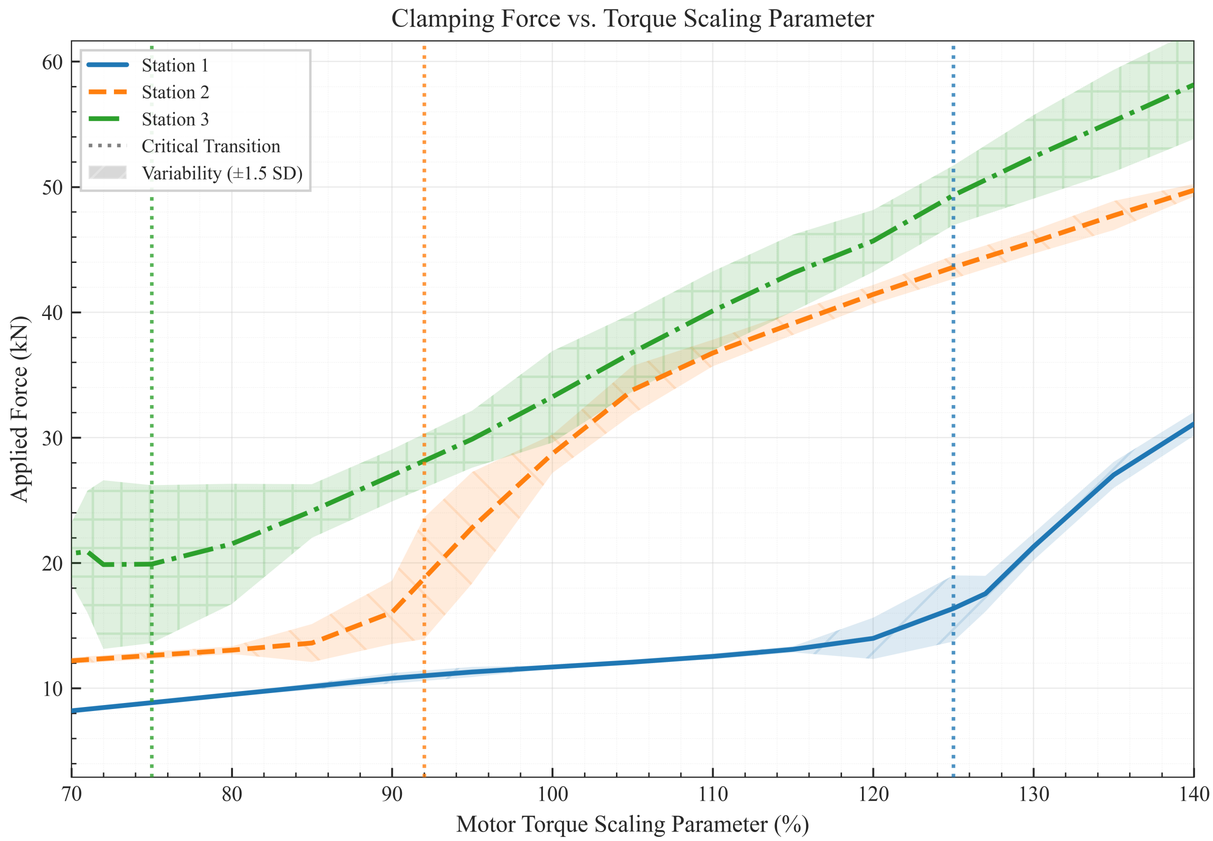

Fig. 3. Clamping Force vs. Motor Torque Scaling Parameter for all stations. Lines show smoothed trends (Station 1: blue solid, Station 2: orange dashed, Station 3: green dash-dot). Shaded bands represent force variability (±1.5 SD) highlighting significantly lower consistency for Stations 2 and 3, particularly evident for Station 3 after a late gear mesh adjustment, below their critical transition points (vertical dotted lines at 92% and 75% respectively). Station 1's higher transition point (125%) and tighter variability demonstrate its inherent stability, linked to higher mechanical resistance. This illustrates the bi-modal stability pattern and the operational challenge at lower force targets.

TABLE II
Consistency Index Before and After Optimization

Station	Before	After	Δ
Station 1	∼0.85	∼0.95	+0.10
Station 2	∼0.21	∼0.95	+0.74
Station 3	∼0.26	∼0.88	+0.62

1) Normalizes for different force levels, allowing direct comparison before and after optimization
2) Provides an intuitive scale (higher is better) with reasonable thresholds (>0.8 considered good)
3) Captures the operational impact of force variations on product quality

X. Final Solution Implementation

The final solution implemented consisted of:

1) Three-button control system:
   - Up button: Quick spindle positioning upward
   - Down button: Quick spindle positioning downward
   - Clamp button: Dedicated clamping operation
2) Higher force target range:
   - Operating force increased from 2 tonnes to 3-4 tonnes
   - Force parameters calibrated for each station
3) PLC timing adjustments:
   - 1-second delay after movement initiation before clamping detection
   - Eliminated false triggers from initial torque spike
4) Fine tuning:
   - Re calibrated the frequency inverter for maximum consistence across all 3-stations
   - Improved station movement responsiveness

After implementation, all three stations exhibited:

- Consistent clamping forces within acceptable range
- Improved operator control and feedback
- Significantly reduced sensitivity to parameter adjustments

XI. Lessons Learned and Alternative Approaches

XI-A. Control System Gain Margin

The system's fundamental issue stemmed from insufficient gain margin after motor upgrades. Larger motors increased system gain without corresponding increases in damping, creating instability particularly in Station 2 and Station 3. This is analogous to a car with an oversensitive accelerator pedal - tiny inputs produce unpredictable, large outputs. Operating at higher forces (3-4 tonnes) effectively moved the system to a more stable region on its response curve, similar to how driving a sensitive car becomes more manageable at higher speeds.

XI-B. Motor Sizing and Mechanical Resistance Balance

When motors were upgraded to "overpower" sticking issues in the original machine, this created a fundamental imbalance in the system. Station 1's naturally higher mechanical resistance provided a fortuitous dampening effect, while Station 2 and Station 3 exhibited instability. Rather than simply increasing motor power, addressing the gain/dampening ratio would have been more effective.

XI-C. Alternative Solution Paths

While the implemented solution proved effective and pragmatic, several alternative engineering approaches, often involving different trade-offs in cost, complexity, and implementation time, could have addressed the core stability issues more fundamentally:

- Installing appropriate sensors for secondary clamping detection
- Implementing advanced adaptive gain controls via the inverter
- Replacing the over-sized motors with motors having better torque control characteristics
- Adding intentional mechanical dampening to Station 2 and Station 3 to replicate Station 1's stability
- Redesigning the clamping mechanism for the actual application requirements

XI-D. Application-Appropriate Design

The original issue began when attempting to test valve types (flanged) that the system wasn't designed for. Equipment modifications should focus on appropriate mechanical redesign for the specific application rather than simply increasing power to force compatibility.

XI-E. Nonlinear System Behavior

The dramatic improvement in stability when operating at higher forces reveals the system's nonlinear response characteristics. The engineering solution wasn't to minimize forces (which seemed intuitive) but to find the optimal operating region where the system exhibited stable behavior despite its inherent design constraints.

XI-F. Mechanical Uniqueness

Even stations built to identical specifications developed meaningful mechanical differences that significantly impacted performance. This highlights the importance of individual calibration and parameter tuning rather than assuming uniformity across identical components.

XII. Recommendations and Broader Implications

This analysis successfully resolved the inconsistencies of the Pekos system and provides a valuable case study. The following recommendations focus on using the methodology used and the insights gained to benefit Ventil more broadly, complementing existing QA procedures, and addressing known challenges in documentation and knowledge capture.

XII-A. Enhancing Validation & Troubleshooting Capabilities

1) Integrate Quantitative Performance Metrics

While standard FAT/IAT checklists verify component presence and basic functionality, complex systems such as the Pekos clamp can exhibit performance variations that are not captured by simple checks. For machines where operational consistency is critical, consider incorporating targeted, data-driven performance metrics (e.g., Consistency Index (CI), force range analysis) during final validation when needed if initial functional tests show potential variability. This provides objective data beyond a simple pass/fail, potentially catching issues before shipping, And strengthening QA documentation and evidence of product conformity.

2) Adopt Data-Driven Analysis for Troubleshooting

The methodology used here (systematic data acquisition, parameter analysis, visualization) proved to be highly effective in diagnosing this complex stability problem. Documenting this methodology and adopting it as a standard approach within Service/Engineering for challenging or recurring performance problems can lead to more efficient evidence-based problem solving compared to iterative field adjustments.

3) Standardize Operator Guidelines

Ensure critical operational nuances discovered during commissioning (like the need for continuous clamping motion on less-damped stations) are clearly documented in user manuals to ensure consistent application performance.

XII-B. Improving Knowledge Management & Design Feedback

1) Establish a Central Repository

Utilize detailed analysis reports like this as foundational pieces for an accessible internal knowledge base. Capture diagnostics, principles, and system behavior to support organizational learning and prevent recurrence.

2) Facilitate Cross-Functional Review

Actively share significant findings from complex analyses (like the ∼20% mechanical resistance impact here) with relevant Engineering teams. Highlighting specific performance-related findings can directly inform future design choices or default parameter selections, leveraging Ventil's flat structure for efficient knowledge transfer.

3) Prevent Cascading Modifications

When components of modified machines (such as upgraded motors of order 8724-13) are standardized for new designs, establish a review process to ensure their suitability for the intended application. This implements proactive risk consideration to prevent unintended consequences when carried forward without reassessment.

XII-C. Broader Implications

1) Mechanical Variation Matters

This case underscores that subtle mechanical differences significantly influence the behavior of the control system. Individual parameter tuning and targeted validation are essential where performance is critical.

2) Value of Systemic Analysis

The data-driven approach revealed nonintuitive system behavior and the critical role of the underlying principles (gain margin, damping), highlighting the efficiency of deeper analysis for complex issues.

3) Collaboration

The final solution involved collaborative effort across disciplines, reinforcing the value of teamwork in implementing analytically derived solutions.

XIII. Conclusion

This engineering analysis documents how an iterative, data-driven approach resolved complex stability issues in the Pekos clamping system. While the final solution—increasing operating forces to 3-4 tonnes and implementing a three-button control system—proved effective, it represents a pragmatic compromise rather than an ideal engineering solution addressing the root cause.

The investigation revealed a critical disconnect between design intent and application reality. The original system was explicitly designed for inner/radial seal testing with minimal clamping force, as evidenced by the technical documentation stating "no linear force on the valve body" and listing clamping force as "not applicable." When the customer began testing flanged valves—which fundamentally require higher clamping forces—this created an application-design mismatch that cascaded into multiple reactive modifications.

Validation testing confirmed that operating at higher forces (3-4 tonnes) moved all stations into a more stable region of their response curves, with Consistency Index improvements of +0.74 and +0.62 for Station 2 and Station 3 respectively. While this solution meets immediate operational needs, it should be acknowledged that more fundamental approaches—such as properly sized motors with appropriate damping characteristics or mechanical redesign for flanged valve testing—would have addressed the core engineering issues more directly.

Appendix

The final optimization involved station-specific fine-tuning of several VFD parameters to ensure consistent performance within the 3-4 tonne target range across all units. Key adjustments from default settings included:

- Deceleration Profile: Deceleration time (P1-04) increased to 0.5 s and Stop Mode (P1-05) set to 'Ramp to Stop' for controlled deceleration and smoother operation on all stations.
- Clamp Detection Threshold (P2-16): This parameter, determining when clamping engages based on motor torque, was tuned individually to compensate for resistance differences and ensure reliable detection without false triggers. It was set to 35% for Station 1 and 25% Station 2 and Station 3. The higher threshold for Station 1 reflects its higher inherent mechanical resistance.
- Force Target Scaling (P2-31): This parameter scales the analog input controlling the overall clamping force target. To achieve comparable clamping forces (3-4 tonnes) across stations despite their resistance differences, significant station-specific scaling was required: 145% for Station 1 versus 102.5% for Station 2 and Station 3. This large difference directly highlights the impact of the mechanical variations on the required control inputs.

A. Key Assumptions

The analysis and solution development were based on several key assumptions:

- Fundemental Design Similarity (Initial Assumption): It was initially assumed that the three stations, being built to the same design specification (VCBT150-SA, Order 30196-24), would exhibit broadly similar mechanical characteristics. Subsequent investigation revealed significant differences in inherent resistance, which became a key factor in the analysis.
- Motor characteristics: We assumed that the upgraded motors (2.2kW G26-100L4) maintained consistent torque-speed characteristics across all units and that their performance aligned with manufacturer specifications.
- Controlled Testing Environment: Testing was conducted under relatively stable factory conditions. It was assumed that major fluctuations in ambient temperature, humidity, or primary power supply did not significantly skew the core comparative results

observed during the testing period. Long-term performance under variable field conditions remains subject to further validation.

- Standardized Test Procedures: For comparative analysis, operator interactions (button presses, valve placement) were performed as consistently as possible according to defined test procedures by a single analyst (the author) to minimize operational variability during the data acquisition phase. The impact of varying operator techniques in regular production is addressed by the standardized operator guidelines recommended.

B. Study Limitations

Several limitations should be acknowledged when interpreting the results:

- Time constraints: Production deadlines necessitated finding a practical solution rather than pursuing a complete system redesign, which might have addressed the root causes more directly.
- Measurement precision: While care was taken to ensure measurement accuracy, the industrial environment introduced some variability that could not be completely eliminated.
- Parameter space exploration: Due to time constraints, not all possible parameter combinations could be tested. The solution represents an optimized point within the explored parameter space rather than a guaranteed global optimum.
- Long-term validation: While the solution has demonstrated stability in initial testing, long-term performance under varied production conditions remains to be fully validated.
- Alternative approaches: Several alternative engineering approaches were identified but not fully explored due to resource constraints. These might offer additional performance improvements in future iterations.