Critical Design Review

MISCE project

Mechatronics for Improving and Standardizing Competences in Engineering

Competence: Mechanical Systems

Experimental platform: Servo-Driven Crank Burnisher

Workgroup: RzuT, UNICA, UCLM, UNICAS

This document is the Critical Design Review of the technical competence ‘Mechanical Systems. Its details the complete design of the Servo-Driven Crank Burnisher.

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1 Introduction

1.1 Scope

This document presents the detailed design of the burnisher developed in the framework of MISCE project.

The final objective is to use the developed platform in the practical lectures of engineering degrees to contribute to the technical competence:

C5. Mechanical systems

which related skills are (see Table I):

Table I. Skills of Mechanical Systems

S5.1.	To understand the different energy conversion process to produce movement
S5.2.	To know to design mechanical system
S5.3.	To know the different movement transmissions
S5.4.	To be able to analyse and optimise a mechanical device
S5.5.	To know the force and torque involved in mechanical systems

1.2 Preliminary definition

Burnishing is a process of localized plastic deformation of a material's surface caused by a smooth, undeformable tool. During burnishing, a spherical or cylindrical element of the tool applies force to the machined surface, displacing irregularities and inducing beneficial compressive stresses, which result in reduced surface roughness and enhanced surface layer strength.

This term refers to the mechanical burnishing tool mounted on a lathe, consisting of a burnishing head with an indenter attached to an arm and a lathe-mounting bracket. The tool is designed in a CAD environment (SolidWorks 2024) and must follow the exact configuration of parts and specified materials as detailed in the provided technical drawings.

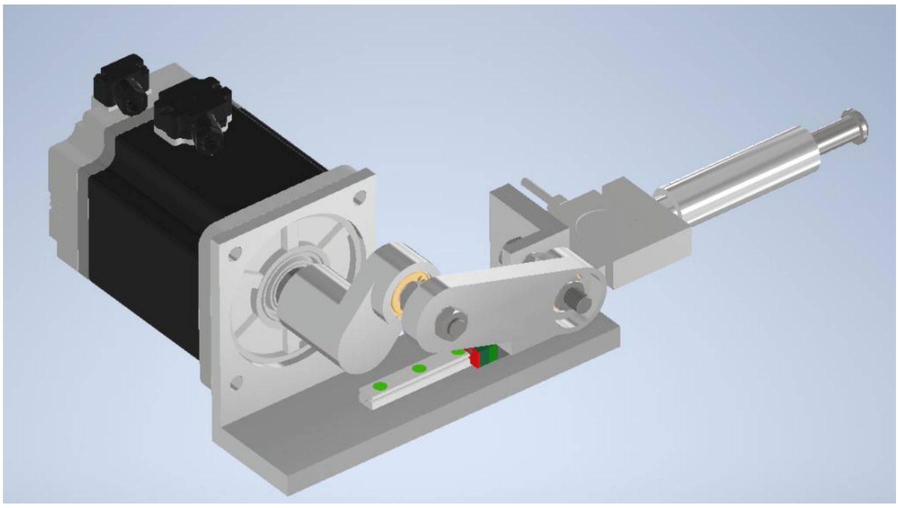

Figure 1. The burnishing tool

1.3 Advantages of the Servo-Driven Crank Burnisher

- **Versatile Operating Modes**: Supports both static (constant force) and dynamic (oscillatory or variable force) burnishing, enabling a wider range of surface treatments and research scenarios.
- **Precise Force Control**: Integrated force sensor and servo feedback allow exact regulation of indentation force, improving repeatability and enabling parametric studies of force–deformation behavior.
- **Automated Motion Profile**: The servo-driven crank mechanism can generate complex motion paths (e.g., sinusoidal, ramped) without manual intervention, enhancing consistency and reducing operator variability.
- **Adaptability**: The modular attachment design fits lathes or other machine tools, permitting the workpiece to either rotate or translate under the burnisher head depending on the process requirement.
- **Data Acquisition Capability**: Real-time force and position data from the sensor and servo system facilitate analysis of dynamic interactions, supporting educational and experimental objectives.

1.4 Disadvantages of the Servo-Driven Crank Burnisher

- **Increased Complexity**: The addition of a servo motor, crank arms, and force sensor introduces more components and potential points of failure compared to a purely mechanical tool.
- **Higher Cost**: Servo systems, sensors, and advanced control hardware substantially raise the capital and maintenance expenses.
- **Setup and Calibration Demand**: Correct alignment of the crank mechanism, calibration of the force sensor, and tuning of servo parameters require specialized skills and time.
- **Control-System Dependency**: Burnishing performance depends on PLC/HMI programming and servo drive configuration; software bugs or misconfigurations can interrupt experiments.
- **Dynamic Instabilities**: At higher speeds or force oscillations, resonance or vibration may occur in the crank arms or lathe carriage, potentially affecting surface quality and requiring damping or speed limits.

1.5 Technical requirements

This section outlines the essential technical requirements for the burnishing tool system to ensure safe, reliable, and precise operation.

1.5.1 Mechanical Requirements

- **Lathe Compatibility**: The burnishing assembly must fit standard lathe tool posts or cross slides with a bracket interface. The mounting bracket should accommodate carriage travel up to 200 mm.
- **Range of Motion**: The crank mechanism must deliver ±10 mm stroke at the indenter, with motion speeds adjustable between 0.1 and 5 mm/s for static and dynamic modes.

- **Force Capacity**: The servo-driven mechanism and load cell assembly must withstand peak forces up to 2 kN without structural deformation.
- **Material Specifications**: All load-bearing components use structural steel (S235JR) unless otherwise specified. The indenter material is hardened tool steel.

1.5.2 Electrical Requirements

- **Power Supply**: 230 VAC ±10%, 50 Hz mains supply via 2.5 mm² cable to the control enclosure.
- **Control Voltage**: 24 VDC for PLC, HMI, and sensor circuits, supplied by Siemens PM1207 power module.
- **Signal Cabling**: 0.5 mm² shielded cable for load cell signals; Cat 5e patch cords for PLC-to-servo-drive and PLC-to-HMI communication.
- **Protection Devices**: 8 A slow-blow fuse for PLC supply; Eaton Z-MS-6.3/2 circuit breaker for servo motor power.

1.5.3 Control and Software Requirements

- **PLC Program**: Siemens SIMATIC S7-1200 CPU 1215C program implementing force feedback loops, safety interlocks, and user-selectable burnishing profiles.
- **HMI Interface**: MTP 400 Unified BASIC panel with screens for parameter entry (force, speed, cycle count), real-time force display, and alarm messages.
- **Communication Protocol**: PROFINET between PLC and servo drive.

1.5.4 Safety and Operational Requirements

- **Emergency Stop**: External E-stop circuit integrated through PLC digital inputs, immediately cutting power to the servo drive and isolating the burnishing head.
- **Protective Guarding**: Transparent polycarbonate shield around the crank linkage area to prevent operator contact during dynamic operation.

These technical requirements form the baseline for design validation, testing protocols, and compliance checks prior to deployment in educational or industrial settings.

2 Hardware design

In this chapter, the detailed hardware design of the burnishing system is described. It encompasses the mechanical structure, servo-driven crank mechanism, control unit enclosure, electrical layout, and material selection. Each subsection provides design rationale, component integration, and manufacturing considerations.

2.1 Mechanical Structure

- **Burnishing Head and Indenter**: The head houses the spherical indenter mounted on a hardened steel plunger. The plunger slides in a bushing to ensure smooth motion. A preloaded spring maintains contact force in static mode.
- **Crank Mechanism**: Composed of two equal-length crank arms (100 mm) connected by a cross pin. The servo motor output shaft drives the primary arm; its motion is transferred to the secondary arm, converting rotational input into linear indenter stroke of ±10 mm.
- **Mounting Bracket**: CNC-milled from 20 mm thick structural steel plate, the bracket interfaces with the lathe tool post via T-slots. Precision dowel pins ensure repeatable positioning.
- **Force Sensor Integration**: An EMS110 S-beam load cell is inserted between the crank arm and the burnishing head. The sensor mounting uses a rigid aluminum adapter plate to minimize parasitic loads.

2.2 Control Unit Enclosure

- **Enclosure Body**: Extruded aluminum profiles with integrated DIN-rail mounting. The PLC, power module, and terminal blocks are arranged to optimize cable routing.
- **Front Panel**: 3 mm DiBond plate machined for HMI cutout, emergency stop button, and load cell quick-disconnect.
- **3D-Printed Components**: PLA handles and corner connectors, designed for ergonomic grip and shock absorption. Printed parts use 100% infill and 0.2 mm layer height for strength.
- **Internal Layout**: Components mounted on removable subpanel for easy servicing. Patch cords and power cables are guided through labeled cable ducts.

2.3 Electrical Design

- **Power Distribution**: Incoming 230 VAC distributes through a main terminal block. Separate circuits feed the PLC (via fuse) and servo drive (via breaker).
- **Signal Wiring**: Shielded pairs for the load cell terminate on a 6-pin terminal block close to the sensor. Cat 5e patch cords connect PLC I/O and HMI ports.
- **Earthing and Shielding**: Enclosure connected to machine tool ground. All shields terminate on a single ground point.

2.4 Material Selection and Manufacturing

- **Structural Components**: Structural steel S235JR for brackets and frames of the burnisher, chosen for weldability and cost. All plates laser-cut and CNC-bent.
- **Wear Parts**: Indenter and plunger made of HRC 60 tool steel, heat-treated for hardness and longevity.

- **3D-Printed Parts**: PLA selected for non-load-bearing elements; easy to print and replace.
- **Surface Finishes**: Steel parts painted with industrial enamel; aluminum parts anodized.

2.5 Assembly and Tolerances

- **Dimensional Tolerances**: ±0.2 mm on milled surfaces; ±0.1 mm for sensor mounting interfaces.
- **Fasteners**: Grade 8.8 steel bolts with lock nuts.
- **Alignment Procedures**: Use dial indicator to align indenter axis within 0.05 mm of lathe centerline.
- **Quality Control**: Post-assembly inspection includes force calibration of load cell, stroke verification, and verification of safety interlock operation.

This hardware design ensures that the burnishing system delivers accurate, repeatable surface finishing in both static and dynamic modes, while facilitating maintenance and future upgrades.

3 Software design

The software architecture for the burnishing system comprises the PLC control logic and HMI interface configuration. It ensures coordinated operation of the servo-driven crank mechanism, force feedback control, user interaction, and fault management.

PLC Control Logic and HMI interface is Implemented in the latest version of Siemens TIA Portal using structured programming (Organization Blocks, Function Blocks, and Data Blocks).

All the programs are attached to software and the assembly instructions.