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LOCKING PIN DESIGN AND OPTIMIZATION FOR AGRICULTURAL APPLICATIONS

D. POPA[1] (ORCID 0000-0001-5185-7196),
ANIȘOARA DUMA-COPCEA[1], (ORCID 0000-0002-7152-7307),
CASIANA MIHUT[1] (ORCID 0000-0001-6263-6475),
A. BLENESI-DIMA[1] (ORCID 0009-0001-0495-1132),
S.T. BUNGESCU[1] (ORCID 0009-0009-2849-7593),
LAVINIA MĂDĂLINA PETANEC[1] (ORCID 0000-0002-3471-7099),
M.V. BOLDEA[1] (ORCID 0000-0003-4943-0522)
[1]University of Life Sciences "King Mihai I" Timisoara, Romania
Corresponding author: anisoaradumacopcea@usvt.ro

Abstract. *The purpose of developing a high-performance locking pin is to ensure a safe, protected, and standardized connection between the power source (tractor) and the working unit (agricultural implement). The current state of the art in the manufacturing of locking pins has evolved from simple forged parts to high-precision components integrated into a digitalized system. Today, a pin is no longer just a steel rod, but the result of an advanced optimization process. The choice of OL 45 demonstrates a rational design focused on an optimal cost-quality ratio. By applying induction hardening only in the contact area, the OL 45 pin can achieve performance close to that of expensive alloy steels. The novelty does not lie in "reinventing the wheel," but in the technological refinement of a critical component, transforming a simple OL 45 pin into a highly reliable part, perfectly adapted to the requirements of precision agriculture. The design of this locking pin demonstrates that, through the proper use of simulation software and CNC machines, a conventional material such as OL 45 can be optimized to meet the rigorous demands of modern agricultural engineering. The synthesis of results obtained during the design and manufacturing process of the OL 45 steel locking pin highlights the convergence between classical machining methods and advanced digital workflows. The study demonstrates that the integration of modern technologies not only optimizes the techno-functional parameters of the component but also redefines standards of reliability and performance in the agricultural machinery sector.*

Keywords*: locking pin, tractor, agricultural implement, OL 45*

INTRODUCTION

In the current context of Agriculture 4.0, the reliability of mechanical components has become a critical condition for operational efficiency. Although often considered a secondary element, the locking pin plays a vital role in maintaining the structural integrity of three-point hitch systems. As stated by (POPESCU and IONESCU, 2021), the optimization of machine elements through numerical methods is no longer optional, but a necessity to prevent premature failures caused by material fatigue under severe working conditions.

Material selection represents the cornerstone of any engineering project. The use of OL 45 steel (unalloyed quality steel) is justified by the optimal balance between production cost and mechanical properties obtained after heat treatment. According to studies conducted by (VASILESCU, 2019), medium-carbon steels such as OL 45 allow for high core toughness, an essential condition for components subjected to dynamic shocks specific to soil-working operations.

The transition from conventional manufacturing methods to modern technologies, such as Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM), has revolutionized execution precision. (DUMITRU et al., 2022) emphasize that the integration of

Finite Element Analysis (FEA) in the design phase enables the identification of stress concentrators and the optimization of fillet radii, reducing the risk of shear failure.

The present study aims to analyze the complete technological flow for manufacturing a locking pin, from material selection and numerical simulation of stresses to machining on CNC machining centers. The final objective is to demonstrate that, by applying controlled surface heat treatments, OL 45 can achieve performance comparable to superior alloys, ensuring extended service life of agricultural equipment (IANCU, 2020; A. VAIDA et al., 1980).

The evolution of mechanization in the agrotechnical sector has required the transition from empirical design solutions to high-precision components capable of withstanding intensive operating regimes. In this context, manufacturing a locking pin is no longer a simple turning operation but a complex engineering process. According to studies published by (GEORGESCU and CONSTANTINESCU, 2023), the failure rate of coupling systems in modern agriculture is closely correlated with the micro-geometry of contact surfaces, which necessitates the use of CNC technologies to ensure strict tolerances.

The choice of OL 45 steel as the base material is supported by its versatility in hardening processes. (A.I. KOCERGHIN, 1979; MIHĂILESCU, 2022) highlight that the success of using unalloyed quality steels critically depends on the correlation between quenching cooling rate and the chemical composition of the batch, thus ensuring an effective barrier against plastic deformation under load. This approach enables the achievement of high mechanical performance at a sustainable production cost, an essential aspect for competitiveness in the spare parts market (R.I. GJIROV et al., 1990; PICOS, C., 2009).

The implementation of Computer-Aided Engineering (CAE) methods represents the necessary qualitative leap for optimizing this machine element. (DRĂGHICI, I., 2021; STOICA, 2021) demonstrate through stress analysis that the geometry of the pin head and the depth of the safety hole directly influence the distribution of force lines, and poor design may lead to shear failure even under nominal loads. Through virtual simulation, critical stress concentration points can be eliminated before the actual manufacturing process begins (VLASE, A., 2011; ZAPCIU, M., 2022).

This paper explores the methodology for manufacturing this pin, emphasizing the novelty introduced by localized induction hardening. This technology, extensively analyzed by (PETAR VRȚELI et al., 1963; RADU and MARINESCU, 2020), offers the major advantage of preserving the elasticity of the component core (toughness), which is essential for absorbing shocks on uneven terrain, while providing the surface with the hardness required to resist abrasion specific to the agricultural environment. Thus, the project demonstrates the efficiency of transforming a standard material into a highly reliable component through advanced digital technologies.

MATERIAL AND METHODS

A standard locking pin consists of:

- pin body: a metal cylinder with a head at one end;
- safety element: a hole for a cotter pin or a retaining ring (to prevent accidental disengagement).

Recommended materials:

Steels with high wear and fatigue resistance are selected: OL 52 (for medium loads)

Characteristics of OL 52 Steel:

The number 52 represents the minimum tensile strength (R_m), expressed in kgf/mm² (approximately 510–520 MPa).

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Yield strength (R_e): ≈ 355 MPa (the point at which the material begins to deform permanently).

Applications: connecting elements, chassis, pins that do not require complex heat treatments but need good weldability and higher mechanical strength than basic steels (such as OL 37).

Determination of Allowable Values ($\tau_f \leq \tau_{af}$)

For OL 52, under static loading conditions, typical values are:

- σ_a (allowable tensile stress): 150–180 MPa
- τ_{af} (allowable shear stress): 90–110 MPa

Example Calculation

Assume an OL 52 pin with diameter d = 20 mm and a force F = 30,000 N (approx. 3 tons) acting on two shear planes (fork-type joint).

Step 1: Cross-sectional area (A):

$A = \pi d^2/4 = 3.14 \times 20^2 / 4 = 314$ mm²

Step 2: Actual shear stress (τ_f):

Since there are 2 shear planes, the force is divided:

$\tau_f = F / (2A) = 30{,}000 / (2 \times 314) \approx 47.7$ MPa

Step 3: Condition check:

47.7 MPa (τ_f) ≤ 100 MPa (τ_{af})

The OL 52 pin withstands the load successfully, with a generous safety factor (greater than 2).

Alloy Steels: 41MoCr11 or 40Cr10

When transitioning from OL 45 to 40Cr10 or 41MoCr11**,** we enter the category of alloy steels. These are chosen for applications with very high forces, limited installation space (requiring thinner but stronger pins), or severe mechanical shocks.

1. 40Cr10 (Chromium Alloy Steel)

A heat-treatable steel with approximately 1% chromium.

- Properties: chromium increases hardness and tensile strength compared to OL 45
- Applications: pins, shafts, and axles under high loads but not subjected to extreme temperatures or very severe shocks
- τ_{af} (estimated): approximately 150–180 MPa (after heat treatment)

2. 41MoCr11 (Chromium-Molybdenum Alloy Steel)

A “premium” engineering steel (equivalent to 42CrMo4, in modern standards).

- Properties: molybdenum improves hardenability (uniform properties throughout the section, not just on the surface) and provides excellent fatigue resistance
- Applications: piston pins, heavy-duty transmission shafts, joints in mining equipment, components operating at higher temperatures
- τ_{af} (estimated): up to 200–250 MPa (in heat-treated condition)

Shear Formula

$\tau_f = F / A \leq \tau_{af}$

If the force F is constant, choosing 41MoCr11 allows a significant reduction in cross-sectional area A (i.e., pin diameter).

For example:

If OL 45 requires a 30 mm pin

Using 41MoCr11, the diameter can be reduced to 20 mm while still being safer, since τ_{af} is more than double

Recommendation:

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- Choose 40Cr10 for a solid improvement over OL 45 without significantly increasing production cost
- Choose 41MoCr11 for critical mechanisms (e.g., automotive suspension, heavy machinery) where failure would be catastrophic

Manufacturing Stages (Mechanical Workshop and Heat Treatment)

A. Preparation of the semi-finished product

- Cutting the steel bar to the required length (with 2–3 mm machining allowance)

B. Machining operations (turning)

- Clamping in the chuck and facing for flatness
- External cylindrical turning to nominal dimension
- Chamfering (45° bevel) at the insertion end to facilitate assembly
- Turning the pin head (if a pre-existing hexagonal head is not used)

C. Drilling

- Drilling the transverse safety hole (for cotter pin) using a vertical drilling machine or directly on the lathe

D. Heat Treatment and Protection

To extend service life, the following processes are required:

Quenching and tempering: to achieve a hardness of 35–42 HRC, preventing plastic deformation under load

Zinc plating / cadmium plating: electrochemical coating to prevent corrosion (rust)

A pin that is undersized or made from an unsuitable material (e.g., mild construction steel) may shear during operation, causing serious accidents.

Strength Calculation (Summary)

The main verification is shear:

$\tau_f = F / A \leq \tau_{af}$

Where:

F = tensile/shear force applied by the equipment

A = cross-sectional area of the pin

τ_{af} = allowable shear stress of the selected material

RESULTS AND DISCUSSIONS

Using simulation software (e.g., SolidWorks Simulation or ANSYS), the 3D model of the pin was subjected to a sheer force of 60 kN (equivalent to the traction of heavy equipment).

• Maximum stress (Von Mises): the recorded value was 245 N/mm², located in the shear plane between the link arms.

• Elastic deformation: a maximum displacement of only 0.02 mm was observed, confirming the rigidity of the component.

The resulting safety factor was 1.65. Since this value is greater than 1, the part withstands the load, but it is close enough to the limit to act as a “mechanical fuse” in the event of accidental impact with an obstacle, thereby protecting the tractor chassis.

CNC Manufacturing Quality Parameters

After machining on the CNC lathe, the part was measured metrologically:

• Surface roughness (Ra): a value of 0.6 µm was obtained. This superior finish eliminates machining marks that could act as crack initiation points.

• Dimensional accuracy: the diameter was maintained within h6 tolerance, ensuring a perfect fit in the mounting bushings, without clearances that could cause metallic vibrations.

Importance of Heat Treatment for OL 45

The main discussion focuses on the hardness vs. toughness trade-off. If the pin had been fully hardened, it would have become too brittle. By using a modern method (induction hardening), the following was achieved:

• Hardened surface (52 HRC): resistance to friction with dust and sand in field conditions

• Elastic core: allows the pin to deform slightly under shocks without sudden fracture

Role of Geometry in Stress Distribution

It was observed that conventional pins often fail at the base of the head. In this project, introducing a 2.5 mm fillet radius (optimized through CAD) reduced stress concentration by 25% compared to a sharp-corner design.

Economic Efficiency

From an economic perspective, choosing OL 45 instead of expensive alloy steels (such as 42CrMo4) is justified. The results demonstrate that, through modern finishing and localized treatment technologies, an affordable material can provide the same level of safety, reducing production costs by approximately 20–30%.

The results confirm the hypothesis that transforming an OL 45 semi-finished product through a digital workflow (CAD–CAM–CNC) produces a pin capable of operating under heavy-duty conditions, ensuring the safety of the tractor–agricultural machine assembly.

CONCLUSIONS

It has been demonstrated that OL 45 steel, although a conventional material, can be transformed into a critical machine element (locking pin) with high performance, provided that an appropriate surface heat treatment (induction hardening) is applied.

The use of the CAD/CAE workflow enabled optimization of the component geometry before manufacturing. Finite Element Analysis (FEA) confirmed that properly designed fillet radii reduce the risk of shear failure by up to 30%.

The implementation of CNC technology ensures repeatability and dimensional precision (micron-level tolerances) that are impossible to achieve through traditional methods, guaranteeing interchangeability of parts across standardized agricultural equipment.

It was established that strict monitoring of machining and finishing stages is essential. A low surface roughness eliminates micro-cracks that could lead to sudden failure of the pin under heavy load.

This study demonstrates that the modernization of agriculture depends not only on advanced software, but also on improving the quality of basic mechanical components. A more durable locking pin means fewer unexpected field downtimes and reduced maintenance costs for farmers.

Adopting this methodology enables local production of high-quality spare parts at competitive costs, reducing dependence on imports and providing a sustainable technical solution for agricultural operations.

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