

Design and Development of a Universal C-Wrench Special Tool for Assembly and Disassembly of Hydraulic Cylinder Nut Covers

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ABSTRACT

Maintenance and repair of hydraulic cylinders, especially in confined areas like those in articulated dump trucks, can be very difficult because of access to tools and safety issues. In this study, the design and development of a Universal C-Wrench, a special tool for the safe and efficient assembly/ disassembly of hydraulic cylinder nut covers without removing the entire cylinder from the equipment were presented. An engineering design process (EDP) was used, which includes problem identification, requirement analysis, conceptual design, design selection, detailed design, prototyping and simulation-based validation. Three different design approaches were formulated, based on mechanical performance using finite element analysis (FEA), cost estimation, and field applicability. The final concept was chosen as Design 2, which was made of SS400 steel and had the lowest safety factor (12.075) that was still above the standard requirement for static load-bearing tools. Other improvements including dimensional changes, structural reinforcement and the implementation of dual handles for increased ergonomics were made based on field use and usability. Overall, the Universal C-Wrench is a versatile and cost-effective tool for servicing hydraulic cylinders in heavy machinery and could be used in other similar industrial applications.

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1. INTRODUCTION

In industrial operations, materials and components are frequently transported, held in place, formed, or pressed. At many sites, mechanical motion is powered primarily by electrical energy. However, in addition to electricity, fluids are also commonly utilized. Fluids and gases can be used to transfer force, generate rotary or linear motion, and power various types of equipment [1,2]. Fluid-based systems are classified into two major types: pneumatic systems, which use compressed gases, and hydraulic systems, which use pressurized liquids as their working medium [3].

A hydraulic cylinder is a type of actuator that converts hydraulic energy into linear force and motion by using pressurized fluid [4-7]. These components are extensively used across various sectors, including construction, automotive, aerospace, forestry, mining, marine, and manufacturing industries [8-10]. Due to their high force output and low maintenance requirements, hydraulic cylinders are ideal for applications that require high linear force in heavy machinery [11,12]. The primary function of a hydraulic cylinder is to transform fluid power into mechanical energy. This is

achieved by directing pressurized hydraulic fluid into one side of a piston, creating mechanical pressure and motion [3]. To service hydraulic cylinders, technicians typically require special service tools (SSTs) [8,13-16]. These are purpose-built tools designed for specific components such as large nuts, hydraulic cylinders, and other specialized assemblies. While these tools significantly facilitate the disassembly and reassembly process, they are generally not widely available in the commercial market and are often tailored to a single component or application.

The disassembly of a hydraulic cylinder requires removing it from the machine and loosening the nut cover using a C-wrench [17-20]. Current hydraulic cylinder disassembly tools tend to be limited in their usability, often lacking effectiveness, and in some cases posing a risk of damaging the component or injuring the technician. Most commercially available SSTs are designed to be used only when the hydraulic cylinder has already been removed from the machine. However, the conventional C-wrench is typically constructed from solid iron with a fixed shape, meaning it can only fit a specific cylinder diameter and cannot be used while the cylinder is still installed. In practice, many mechanics fabricate their own versions of C-wrenches using sheet metal. However, such homemade tools often lack compliance with safety standards and are limited to a single cylinder size, increasing the risk of hand injury during operation. Moreover, in actual working conditions, such as those observed at PT Nusantara Inti Pratama (NIP) and PT Sumber Rejeki Ekonomi (SRE), mechanics are often forced to loosen or tighten hydraulic cylinder components by striking them with metal rods and hammers. This approach not only risks damaging the cylinder's thread but also increases the likelihood of mechanical failure and operator injury.

Some e-commerce platforms, particularly those based in China, offer hydraulic cylinder disassembly tools with slightly different mechanisms. These tools can be used either in free space or when the cylinder has been removed, but they have strict limitations. For example, one model supports only internal grooves and a maximum cylinder diameter of 95.25 mm and costs around 46 on marketplace [21]. Another model supports diameters up to 145 mm and costs around USD 57 [22]. Both models remain limited in scope and are not adaptable to a wide range of cylinder sizes or working conditions.

The novelty of this research lies in the design and development of a universal special service tool capable of disassembling and reassembling hydraulic cylinder nut covers in situ (while still installed) or off-equipment and accommodating various cylinder sizes. To date, the servicing of hydraulic cylinders has been hindered by the unavailability of versatile and safe tools, with most tools on the market being suitable only for specific sizes or usable only after removal. This research aims to address these limitations by introducing a tool that is flexible, safe, and ergonomic. The proposed tool will allow technicians to work more efficiently and safely, minimizing the risk of component damage and personal injury. Furthermore, the tool is designed to eliminate reliance on substandard conventional methods such as hammering or using non-standardized C-wrenches. Given the importance of safety and time efficiency in heavy equipment maintenance, the development of this tool is expected to improve productivity and reduce operational costs by minimizing equipment downtime and component failures. Thus, this study holds practical significance and is highly relevant for industries that rely heavily on hydraulic systems, particularly in construction, mining, and manufacturing sectors [17, 23-26].

2. MATERIALS AND METHOD

In this study, engineering design process (EDP) [27-29] is employed to ensure the development of the universal C-Wrench has met the necessary condition and applicable in various condition. The process includes: (1) problem identification, (2) requirement analysis, (3) conceptual design, (4) design selection, (5) detailed design and engineering analysis, (6) prototyping, and testing and validation. The EDP process is depicted in Fig. 1. The process begins with identifying the limitations of existing tools used for hydraulic cylinder servicing, particularly in terms of inefficiency, limited adaptability to different cylinder sizes, and potential safety hazards. These issues were confirmed through field observations and interviews with relevant stakeholders, including senior mechanics, vendor technicians, and maintenance supervisors. Subsequently, a requirement analysis was conducted to translate user needs into technical specifications, such as torque resistance, material

strength, dimensional compatibility, and safety standards. These specifications guided the conceptual design phase, where several alternative designs were developed using 3D CAD modelling and the simulated with Finite Element Analysis that is used as one of the criteria used for selecting design for prototyping. To select the most appropriate concept, the criteria such as functionality, manufacturability, ergonomics, safety, and cost also included, thus ensure that every important aspect from the tools is considered. A prototype was fabricated using suitable manufacturing techniques, enabling hands-on assessment of the tool's functionality, fit, and ergonomics. Finally, testing and validation were conducted in an actual workshop environment, during which the prototype was used to perform disassembly and reassembly operations on hydraulic cylinders. Feedback from technicians was collected to evaluate ease of use, safety, and operational efficiency, and any deficiencies noted during testing were considered for future design improvements.

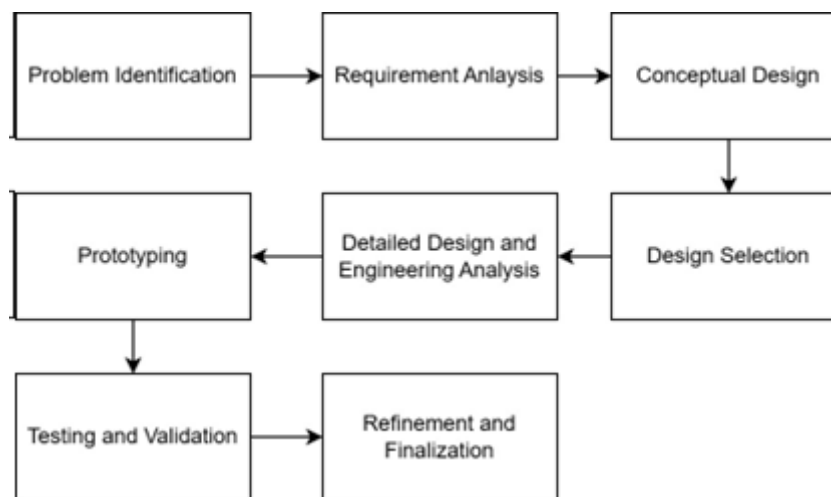


Figure 1. Engineering design process implemented in this study.

Three different design concepts (Design D1, D2, and D3) were developed and each was designed to meet the practical needs of servicing hydraulic cylinder nut covers without necessitating removal of the cylinder unit from the heavy machinery. The three designs all aim at covering a hydraulic cylinder diameter range from 170 to 230 mm, and especially at cylinders that are not easy to reach, like the steering cylinders in Volvo Articulated Dump Truck A40 series, on which conventional C-wrenches cannot be used. The alternative designs D1, D2 and D3 are illustrated in Fig. 2 and the details of the parts are shown in Table 1.

The typical design of the Alternative Design D1 is a comprehensive and modular design set up with a Main Part and a Secondary Part as the main structure. Two complete sets of removable connecting rods, both in 6 sets, offer high flexibility and adjustability. These rods are installed with threaded connecting method: Connecting Rod 2 is directly threaded at the Secondary Part; Connecting Rod 1 is threaded with a connecting rod and nut on the Main Part. These connectors are longer in length from 300 mm to 400 mm, which enables the tool to reach into very deep cylinders in the machine frame. Six M12 Locking Bolts, twelve M12 Nuts and twelve sets of M8 Adjuster Bolts and Nuts make this design mechanically secure and multi point adjustable for high torque. This modular and configurable design lends itself to use in the field where flexibility and long reach are paramount.

Alternative Design D2 is a structure, that is simpler, but has the same function. It is composed of a Main Part and a Secondary Part, like Design D1, except for the absence of detachable connecting rods and instead, the Secondary Part is directly integrated or welded to the Main Part by means of oval shaped connectors. These six fixed rods are made by the common bolt and nut, which could be connected to the Main Part with high rigidity and ease of assembly. It also has four different extension lengths: 257 mm, 307 mm, 357 mm, 407 mm and 440 mm, which allows it to be used in a variety of maintenance situations. Six M12 Locking Bolts are used for the structural parts and eight of M6

Adjuster Bolts and Nuts provide moderate adjustability for various cylinder sizes. The fixed connector approach provides enhanced ease of use and reduces reconfiguration time resulting in user-friendly tool during repetitive servicing operations.

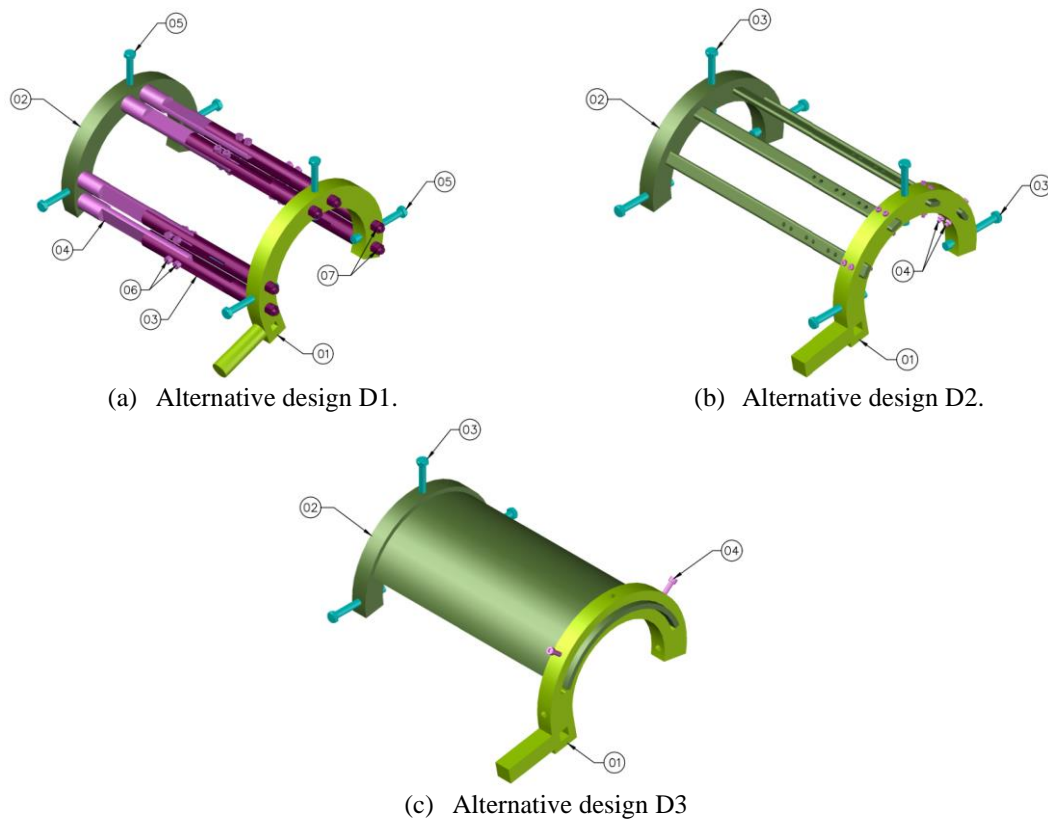


Figure 2. Alternative design proposed in this study namely D1, D2, and D3 with numbering parts.

Table 1. Detailed parts of the corresponding alternative design namely D1, D2, and D3 as presented in Fig. 2.

No. Parts	D1 / Qty. (pcs)	D2 / Qty. (pcs)	D3 / Qty. (pcs)
1	Main parts / 1	Main parts / 1	Main parts / 1
2	Secondary parts / 1	Secondary parts / 1	Secondary parts / 1
3	Connecting rods 1/ 6	Locking bolts (M12) / 6	Locking bolts (M12) / 3
4	Connecting rods 2/	Bolt and nut adjuster (M6) / 8	Bolt and nut adjuster (M6) / 2
5	Locking bolts (M12)/ 6	-	-
6	Bolts and nut adjuster (M8)/ 12	-	-
7	Nut (M12) / 12	-	-

Alternative Design D3 represents the most minimalistic configuration among the three concepts. It retains the basic structure of a Main Part and a Secondary Part, but the connection system is simplified using only three M12 Locking Bolts and two sets of M6 Adjuster Bolts and Nuts. The connecting rod is formed from a single solid piece of 10-inch pipe, directly joined or welded to the Secondary Part and fastened to the Main Part via bolt-nut mechanisms. Although this design sacrifices flexibility and adjustability, it provides excellent strength and rigidity for single-purpose or standardized servicing tasks. The simplicity of Design D3 also translates to reduced manufacturing costs and easier handling in limited-space environments, albeit with less adaptability to varying cylinder geometries.

3. RESULTS AND DISCUSSIONS

a. User requirement analysis

The interview process was conducted through direct face-to-face interaction with relevant stakeholders and was structured into three main stages. The first stage involved presenting the background and purpose of the research. This was followed by a detailed discussion regarding both the actual and expected procedures in the maintenance of hydraulic cylinders, particularly focusing on the challenges encountered in the field. The final stage comprised a summary of the respondents' feedback and a confirmation check to identify any missing information, with additional input incorporated into the final dataset. To explore the topic in greater depth and to collect conceptual data for the development of alternative designs, the author also distributed a structured questionnaire via Google Forms. This method was used to ensure accurate interpretation of the respondents' input, avoiding bias or misrepresentation of the qualitative data obtained during the interviews. In particular, senior mechanics from the Plant Department—who are the main personnel responsible for executing hydraulic cylinder repairs—were involved in completing the questionnaire. Their insights were critical in identifying operational challenges and capturing end-user expectations in a comprehensive manner.

Based on the insights gathered from the interviews and questionnaires, several product constraints were established to guide the development process of the Universal C-Wrench. These constraints were divided into two categories: general constraints and detailed constraints. The general constraints serve to define the boundary conditions and baseline requirements applicable across all potential design alternatives. These include: (a) the tool must be manufactured using materials that are easily sourced from local vendors or partner workshops, specifically SS400, S45C, and SKD11 steel grades; (b) the tool must be operable in confined spaces, particularly in areas such as the steering cylinder compartment of the Volvo A40 Series articulated dump trucks; and (c) the tool must be designed in a manner that prevents damage to adjacent components and eliminates any risk of injury to the mechanic during operation.

Meanwhile, the detailed constraints were formulated to refine the specific design requirements and ensure that each proposed alternative meets user expectations. These include: (a) the tool must be user-friendly and intuitive to operate; (b) it must possess sufficient mechanical strength to endure operational loads; (c) it must exhibit adequate durability for long-term use; (d) the tool should allow for straightforward assembly and disassembly; (e) it must be easy to maintain with minimal effort or cost; and (f) the overall production cost should remain low to ensure economic feasibility. These constraints collectively serve as the foundational design criteria for evaluating the suitability and effectiveness of the proposed Universal C-Wrench concepts in real-world applications.

b. Cost analysis

The estimated production costs for each of the three Universal C-Wrench design alternatives were obtained based on quotations provided by Citra Lesmana Teknik, a fabrication vendor located in Sukabumi, Indonesia. The quotation includes costs for both material procurement and fabrication services. Each design alternative was evaluated using three different material options: SS400, S45C, and SKD11, providing a comprehensive comparison across material quality and pricing.

Cost estimation for material is listed in Table 2. For Design 1, the use of SS400 results in a material cost of IDR 1,800,000 and a fabrication service fee of IDR 1,700,000, totaling IDR 3,500,000. When using S45C, the cost increases to IDR 2,300,000 for material and IDR 2,550,000 for fabrication, with a total of IDR 4,850,000. For Design 2, SS400 is the most economical choice, with a material cost of IDR 1,000,000 and a fabrication cost of IDR 1,700,000, giving a total of IDR 2,700,000. Using S45C increases the cost to IDR 3,650,000, while employing SKD11 results in a cost of IDR 4,400,000. Design 3, though more compact, still incurs a cost of IDR 3,200,000 when using SS400 and IDR 4,300,000 with S45C.

Table 2. Cost analysis considering both materials and processing costs.

Design	Materials	Type of cost	Price (IDR)	Total cost (IDR)
D1	SS400	Material	1,800,000	3,500,000

	S45C	Processing service	1,700,000	4,850,000
		Material	2,300,000	
D2	SS400	Processing service	2,550,000	2,700,000
		Material	1,000,000	
	S45C	Processing service	1,700,000	3,650,000
		Material	1,450,000	
	SKD11	Processing service	2,200,000	4,400,000
		Material	2,400,000	
D3	SS400	Material	1,200,000	3,200,000
		Processing service	2,000,000	
	S45C	Material	2,000,000	4,300,000
		Processing service	2,300,000	

Among all evaluated combinations, the lowest total production cost is achieved with Design 2 using SS400 material, amounting to IDR 2,700,000. As a point of reference, a comparative quotation was also requested from an alternative fabrication vendor located in Depok, Mekka Engineering. The quotation from this vendor indicated a cost of IDR 7,905,000 for a comparable product, representing a price difference of IDR 5,205,000, or nearly twice as expensive as the quotation from Citra Lesmana Teknik.

The detailed breakdown of the lowest-cost configuration (D2 using SS400) is as follows. The total cost of parts amounts to IDR 962,600, which includes:

1. Main Part (1 unit): IDR 380,000
2. Secondary Part (1 unit): IDR 380,000
3. Steel plate (9 mm × 32 mm × 440 mm, 3 units): IDR 120,000
4. Handles (2 units): IDR 30,000
5. Pads (6 units): IDR 30,000
6. Pins (6 units): IDR 600
7. M12 Bolts (6 units): IDR 18,000
8. M8 Bolts (4 units): IDR 4,000

In addition to component costs, the fabrication service fee for this configuration is IDR 1,749,400, leading to a total production cost of IDR 2,712,000. This cost-efficient outcome validates the feasibility of producing a high-quality, functionally effective Universal C-Wrench within a limited budget, provided that appropriate material choices and vendor selections are made.

c. Finite element analysis

Based on the comprehensive simulation results as Depicted in Table 3 and technical considerations, Design 2 was ultimately selected as the optimal configuration for the development of the Universal C-Wrench. The simulation results as depicted in Table 3 are simulated with one material, i.e. SS400, thus all the parameters can be considered the same. The selection was made after evaluating mechanical performance, cost efficiency, and applicability in real-world scenarios. Among the three alternatives, Design 2 achieved a balanced combination of strength, safety, and affordability, making it the most viable option for field application.

The finite element analysis showed that Design 2 performed better than Design 1 in terms of structural integrity. While Design 1 exhibited slightly lower deformation in certain components, it failed to meet the minimum recommended safety factor of 1.5, with a recorded value of 0.927. In contrast, Design 2 achieved a safety factor of 12.075, significantly above the required threshold, indicating that the design is highly reliable even under unexpected peak loads. Additionally, when compared to Design 3, which showed an even higher safety factor (1.42 minimum, 13.96 average), Design 2 maintained a favorable structural behavior while being significantly more economical. For completion purpose, we also run simulation in design D2 with variation in materials. The results summary is listed in Table 4.

Table 3. Finite element analysis results of the three alternative designs with the value on stress analysis and total deformation analysis.

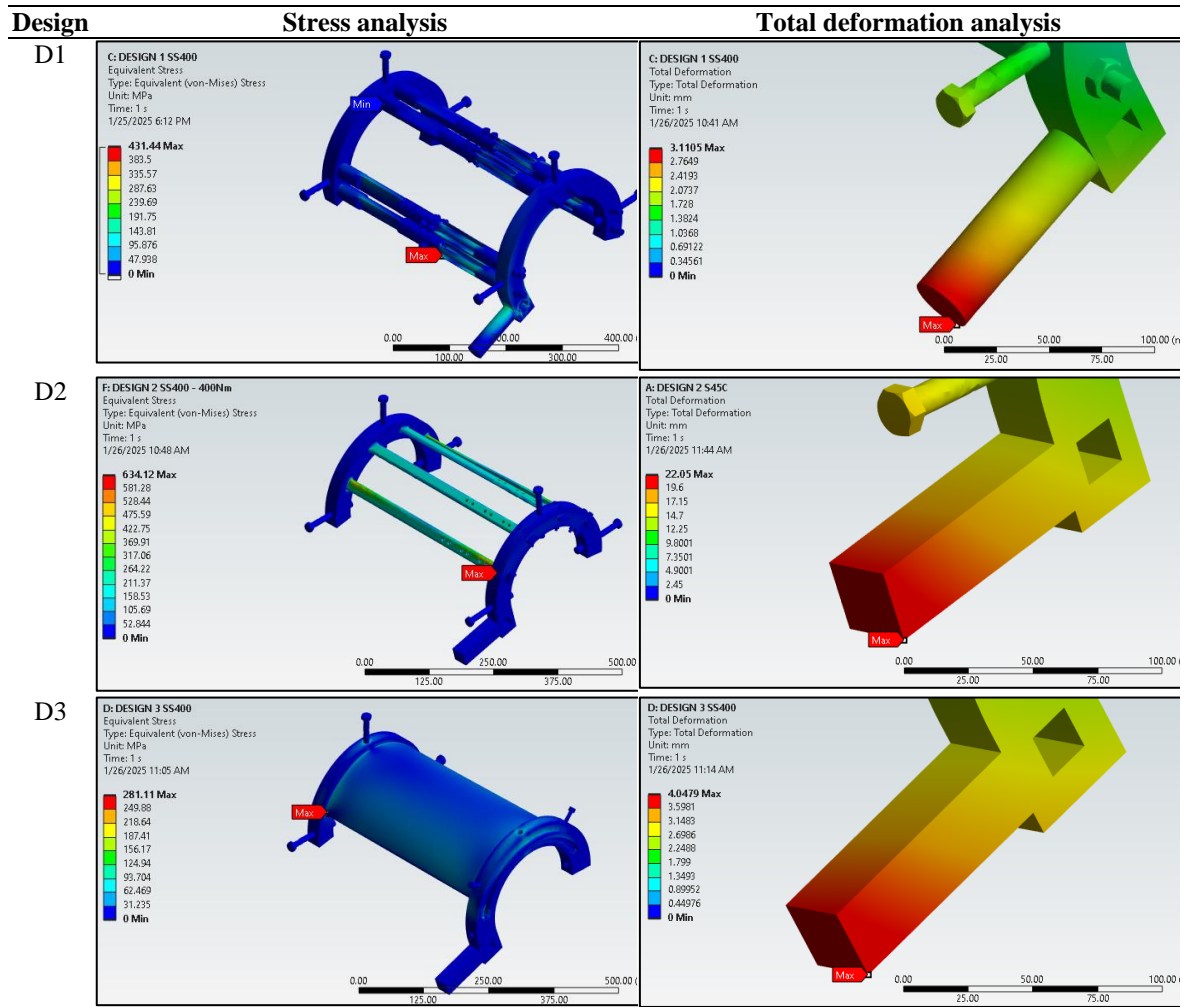


Table 4. Summary of finite element analysis results for design D2 with variation in materials, they are SS400, S45C, and SKD11.

No.	Simulation parts	Parameters	SS400	S45C	SKD11
1	Locking bolt	Stress (MPa)	0	0	0
		Strain (mm)	0.0000053418	0.0000048331	0.000004411
		Tot. deformation (mm)	0.00000054955	0.0000004659	0.00000034697
2	Connecting rod	Stress (MPa)	415.39	379.24	375.73
		Strain (mm)	0.0022254	0.0018532	0.002022
		Tot. deformation (mm)	9.5365	8.6479	9.4551
3	Handle	Stress (MPa)	36.151	35.128	36.823
		Strain (mm)	0.00015572	0.00013652	0.000162555
		Tot. deformation (mm)	24.372	22.05	24.086
4	Safety Factor (Standard: 1,5 ~ 2)	Minimum	0.63079	0.80748	0.41193
		Maximum	15	15	15
		Average	12.075	12.376	11.08
5	Cost estimation	(IDR)	2,712,000	3,650,000	4,400,000

From the simulation standpoint, Design 2 demonstrated moderate stress and strain distribution across critical regions. The connecting rod in Design 2 was subjected to a maximum stress of 415.39 MPa, slightly lower than Design 1 (431.44 MPa), and a total deformation of 9.5365 mm, which,

although relatively high, was within acceptable limits for static load tools. The handle and locking bolts also exhibited tolerable levels of stress and deformation, ensuring mechanical reliability during operation. More importantly, Design 2's geometry and assembly configuration make it suitable for in-situ maintenance tasks, particularly in confined spaces such as the hydraulic steering cylinder compartment on Volvo Articulated Dump Trucks (A40 series).

d. Selected design and design refinements

From an economic perspective, design D2 using SS400 material resulted in the lowest total production cost, estimated at IDR 2,712,000, including both material procurement and fabrication. This is significantly more affordable compared to Design 1 (IDR 3,500,000) and Design 3 (IDR 3,200,000), while still fulfilling functional and safety requirements. Additional material options such as S45C and SKD11 were also analyzed. While these materials offer higher mechanical strength and wear resistance, the cost increase did not yield proportional performance gains for this specific application. Thus, SS400 remains the most cost-effective and structurally adequate choice, particularly when availability and ease of fabrication are considered.

The final configuration of design D2 was refined to enhance its mechanical efficiency, usability, and structural rigidity based on feedback from field testing and iterative design evaluation. The revised version maintains the core functional advantages of the original D2—namely its ability to perform assembly and disassembly of hydraulic cylinder nut covers without removing the cylinder from the equipment—while optimizing the number and configuration of components for improved manufacturability and operational reliability. Detailed figure can be seen in Figure 3 with numbered parts, whilst the detailed engineering drawing document is attached as supplementary materials. Key improvement of the design is as follows.

1. Main Parts (No. 01): This is the central structural component of the tool, responsible for bearing the applied torque during operation. Manufactured from SS400 plate, the Main Part features mounting interfaces for the handles and provides threaded holes to secure the locking bolt M12 Short (No. 3) and Long (No. 4) locking bolts. It also acts as the fixed base for radial adjustment and positioning.
2. Secondary Parts (No. 02): The Secondary Part functions as the adjustable arm that engages with the cylinder nut. It slides and locks into place via the locking bolts and interfaces with Spring Pins (No. 6) and Pads (No. 5) for firm and secure contact. This component is crucial for adapting the tool to different diameters and ensures multi-point engagement to avoid slippage.
3. Locking Bolts M12 – Short (No. 03) and Long (No. 04): A total of six M12 locking bolts, which is three short and three long, are distributed symmetrically around the tool to anchor the Main and Secondary Parts together. The varying lengths accommodate different nut depths and access clearances. These bolts provide axial clamping force and play a significant role in distributing the load during torque application.
4. Pads (No. 05): Each bolt is paired with a Pad at the contact interface with the nut cover. These pads are fabricated from medium-hardness steel and are slightly contoured to match the curvature of the nut surface. Their purpose is to prevent surface damage, reduce local stress concentration, and improve grip during both clockwise and counterclockwise rotation.
5. Spring Pins (No. 06): Installed into the Secondary Part, these six spring pins serve as retention mechanisms and safety locks. They help maintain the Secondary Part's alignment under load, absorb minor vibrations, and ensure consistent radial positioning during repeated use.
6. Adjuster Bolts M8 (No. 07): The four M8 adjuster bolts allow for fine-tuning of the span between the Main and Secondary Parts. This adjustability is critical to ensure a tight fit on cylinder nuts of varying sizes, enabling a more universal application of the tool without the need for redesign or retooling.
7. Handles (No. 08): Two detachable Handles are mounted on the outer frame of the Main Part, ergonomically positioned to facilitate torque application by the technician. These handles are designed to be gripped comfortably and provide leverage when rotating the tool manually. They can also be detached for access in constrained spaces.

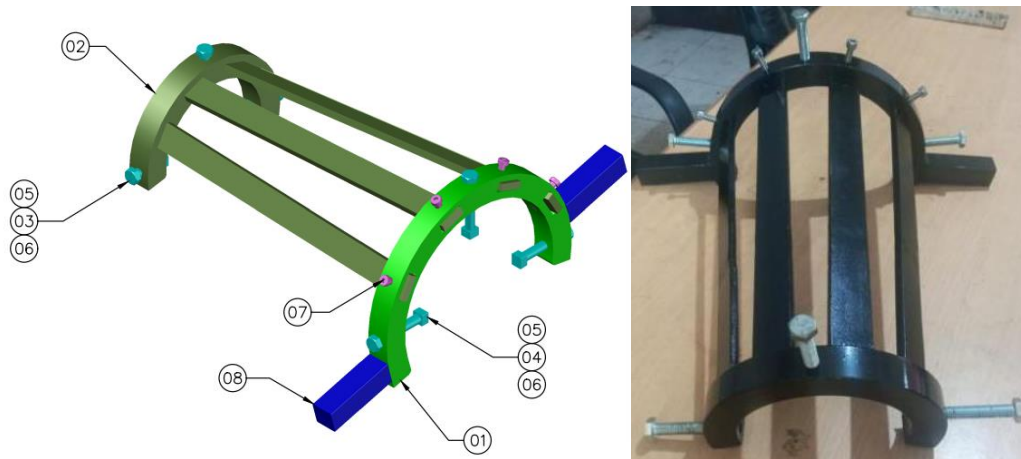


Figure 3. Final design D2 after refinement and its corresponding prototype.

Several design adjustments were implemented in the final iteration of the Universal C-Wrench to improve functionality, manufacturability, and field usability. One major change involved reducing the outer diameter of the Secondary Parts from 290 mm to 215 mm to ensure compatibility with confined spaces in the Volvo A40 Series Articulated Dump Truck, which offers only 50 mm of clearance vertically and 70 mm laterally. This modification allows the tool to be used without disassembling the hydraulic cylinder from the equipment. To reduce potential stress concentrations identified in previous simulations, the alignment holes on the Secondary Part were removed. The conical geometry resulting from the downsizing further justified this removal, as it mitigated the risk of weakening the connection between the threaded bars and the sloped profile of the Secondary Part. In parallel, the width of the connecting bars was increased from 24 mm × 9 mm to 34 mm × 13 mm. This enhancement improves structural integrity, especially under load, while maintaining material availability and fabrication efficiency using standard profiles commonly found in regions like JABODETABEK (Jakarta, Bogor, Depok, Tangerang, Bekasi) and South Kalimantan.

The Main Part was also revised to eliminate the central hole that previously served as a $\frac{3}{4}$ -inch handle extension point. This change was made to facilitate easier internal thread tapping during production. It also allowed the welding of the handle after tapping, avoiding structural weakness that might occur if the handle were mounted near an open hole. Additionally, dual handles were introduced on both sides of the wrench to enable 360° rotation without disengaging the tool, improving ergonomics and efficiency during operation. Further refinement included adding multiple bolt length options, which expanded the tool's operational range from the initial 170–230 mm to a broader diameter span of 115–230 mm, increasing versatility for different hydraulic cylinder sizes. Lastly, the pad design was modified to increase the contact surface area with the hydraulic cylinders groove, enhancing grip strength and minimizing slippage during high-torque applications.

e. Usage illustration

The illustration of the tool's usage, as shown in Figure 4, begins with the repositioning of the articulated dump truck unit (4a). If the left-side hydraulic steering cylinder is to be serviced, the steering system must first be fully turned to the right; conversely, for the right-side cylinder, the steering must be fully turned to the left. The steering cylinders are located behind the tractor head, directly beneath the cabin. It is essential to clear the area of any mud or debris to prevent interference during the repair process (4b). Once the worksite is clean, a cylinder support device such as a chain block should be installed to secure the cylinder. Following this, the bearing and torque rod attached to the piston rod must be carefully removed, thus special attention is needed here to avoid damage to the piston rod during disassembly. When all preparations have been completed and the area is secure, the Universal C-Wrench can be used to remove the hydraulic cylinder nut cover (4c). During this operation, it is critical to ensure that the pad of the tool grips the cylinder groove securely, as improper engagement could result in slippage and potential injury or component damage during high-torque application. Albeit using this tool by the operator still considered as manual operation, however using

this tool with this approach will significantly reduce the risk of damage to hydraulic components and minimizes potential harm to the operator during the removal process. Moreover, it contributes to increased operational productivity, particularly in field conditions where maintenance is conducted directly on-site. In such scenarios, the number of vehicles, each equipped with one or more hydraulic cylinders, can be vary and substantial, making efficient and safe disassembly tools critically important for maintaining the heavy vehicle uptime and reducing overall maintenance time.

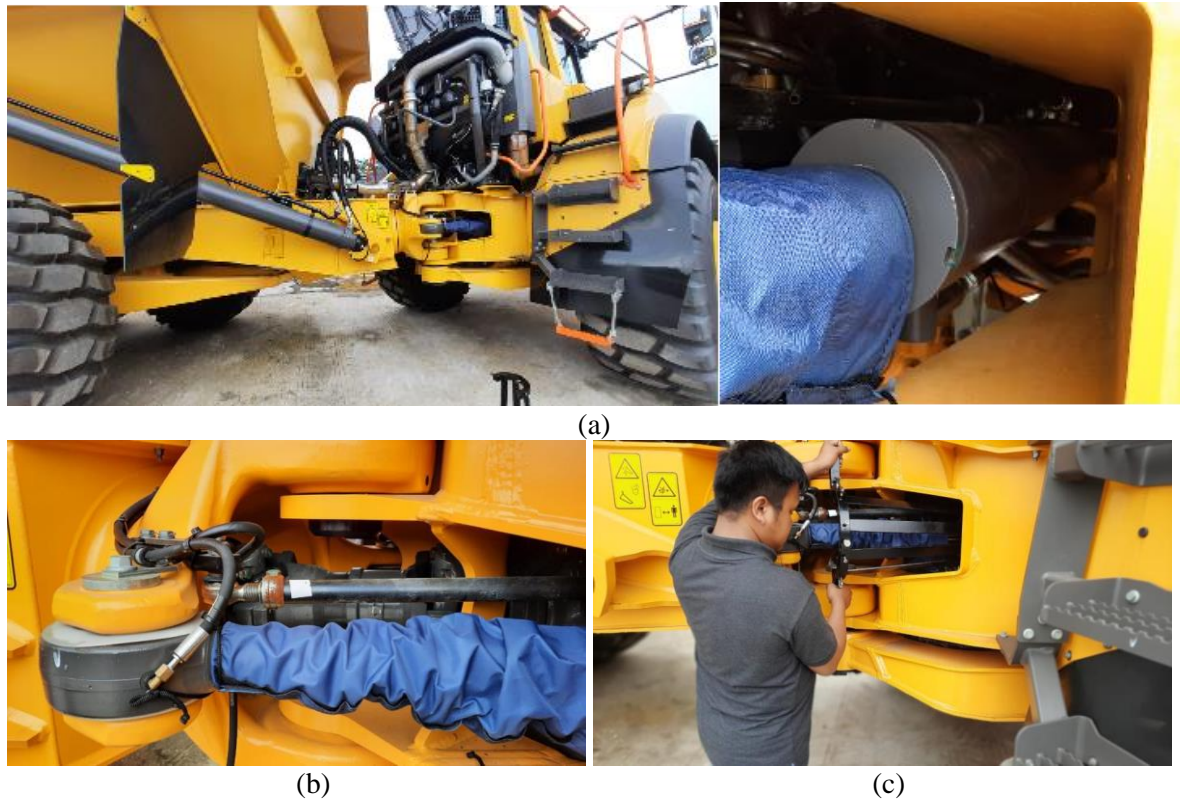


Figure 4. Usage illustration of the universal C-Wrench special service tool for assembly and disassembly of hydraulic cylinder nut covers (a) location of the hydraulic cylinder, covered in blue, (b) detailed location of hydraulic cylinder, clearance of working area, and (c) disassembly of hydraulic cylinder.

4. CONCLUSIONS

This study successfully designed and developed a Universal C-Wrench special service tool tailored for the safe and efficient disassembly of hydraulic cylinder nut covers in heavy equipment. The application of the engineering design process facilitated the creation of three viable design alternatives, each evaluated through structural analysis and cost comparison. Design 2, made of SS400 material, emerged as the optimal solution, offering high mechanical performance with a safety factor of 12.075 and the lowest production cost at Rp 2,712,000. Final revisions enhanced tool compatibility, structural strength, and operational flexibility, enabling usage in constrained spaces such as the steering cylinder area of the Volvo A40 Series articulated dump truck. The incorporation of field-based feedback through interviews and questionnaires strengthened the design's practical relevance. This tool effectively reduces the reliance on improvised or unsafe methods such as hammering, minimizes the risk of equipment damage and technician injury, and improves maintenance efficiency. The developed Universal C-Wrench stands as a reliable and scalable solution for hydraulic cylinder servicing needs within the construction, mining, and heavy-equipment sectors.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS CONTRIBUTION

Agung Gema Muhazir contributed to the initial design development, conducted simulation analysis, and was responsible for prototyping activities. M. Zaenudin conceptualized the research framework, performed data collection, and led the manuscript writing. Y.K.P. Saleh was involved in design refinement, simulation execution, data collection, and vendor coordination. M.N. Mohammed provided overall supervision, contributed to manuscript writing, and performed critical revisions of the paper. All authors have read and approved the final version of the manuscript.

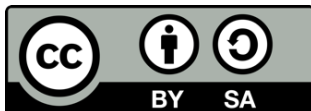
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REFERENCES

- [1] G. ECKART, "ACTUATORS," *FLUID*, vol. 9, no. 10, pp. 35-7, October, 1975, 1975.
- [2] J. Pustavrh, M. Hočevár, P. Podržaj, A. Trajkovski, and F. Majdič, "Comparison of hydraulic, pneumatic and electric linear actuation systems," *Sci Rep*, vol. 13, no. 1, 2023, doi: 10.1038/s41598-023-47602-x.
- [3] A. Salam, *Fundamentals of Pneumatics and Hydraulics*. 2022. doi: 10.1007/978-981-19-0855-2.
- [4] Y. TAKAHASHI, Y. SASAKI, T. KOIKE, and K. YAMAGUCHI, "Fundamental Properties of Oil Hydraulic Multiple Function Cylinder.," *Shigen-to-Sozai*, vol. 109, no. 11, 1993, doi: 10.2473/shigentosozai.109.885.
- [5] S. Ketelsen, T. O. Andersen, M. K. Ebbesen, and L. Schmidt, "A self-contained cylinder drive with indirectly controlled hydraulic lock," *Modeling, Identification and Control*, vol. 41, no. 3, 2020, doi: 10.4173/MIC.2020.3.4.
- [6] L. Solazzi, A. Buffoli, and R. Formicola, "The multi-parametric weight optimization of a hydraulic actuator," *Actuators*, vol. 9, no. 3, 2020, doi: 10.3390/ACT9030060.
- [7] A. F. Hawary and M. I. Ramdan, "Hybrid Hydraulic Vehicle Parameter Optimization using Multi-Objective Genetic Algorithm," *International Journal of Automotive and Mechanical Engineering*, vol. 16, no. 3, pp. 7007–7018, Oct. 2019, doi: 10.15282/IJAME.16.3.2019.13.0525.
- [8] Y. Yang, L. Ding, J. Xiao, G. Fang, and J. Li, "Current Status and Applications for Hydraulic Pump Fault Diagnosis: A Review," 2022. doi: 10.3390/s22249714.
- [9] P. GAO, T. YU, Y. ZHANG, J. WANG, and J. ZHAI, "Vibration analysis and control technologies of hydraulic pipeline system in aircraft: A review," 2021. doi: 10.1016/j.cja.2020.07.007.
- [10] W. Chen, X. Wang, F. Zhang, H. Liu, and Y. Lin, "Review of the application of hydraulic technology in wind turbine," 2020. doi: 10.1002/we.2506.
- [11] Y. Hao, L. Xia, L. Quan, B. Zhao, H. Cheng, and X. Xiong, "Research on Characteristics of Heavy-load Lifting Machinery Based on Hydraulic-gas Energy Storage and Closed Displacement Controlled System," *Jixie Gongcheng Xuebao/Journal of Mechanical Engineering*, vol. 55, no. 16, 2019, doi: 10.3901/JME.2019.16.213.
- [12] Y. Hao, L. Quan, H. Cheng, L. Xia, L. Ge, and B. Zhao, "Potential energy directly conversion and utilization methods used for heavy duty lifting machinery," *Energy*, vol. 155, 2018, doi: 10.1016/j.energy.2018.05.015.
- [13] V. V. Shanbhag, T. J. J. Meyer, L. W. Caspers, and R. Schlanbusch, "Failure Monitoring and Predictive Maintenance of Hydraulic Cylinder-State-of-the-Art Review," 2021. doi: 10.1109/TMECH.2021.3053173.
- [14] S. Gupta, M. Khosravy, N. Gupta, H. Darbari, and N. Patel, "Hydraulic system onboard monitoring and fault diagnostic in agricultural machine," *Brazilian Archives of Biology and Technology*, vol. 62, 2019, doi: 10.1590/1678-4324-2019180363.

- [15] Q. Zeng, W. Liu, L. Wan, C. Wang, and K. Gao, "Maintenance Strategy Based on Reliability Analysis and FMEA: A Case Study for Hydraulic Cylinders of Traditional Excavators with ERRS," *Math Probl Eng*, vol. 2020, 2020, doi: 10.1155/2020/2908568.
- [16] M. Abubakar Tadda, A. Ahsan, M. Imteaz, A. Shitu, U. Abdulbaki Danhassan, and A. Idris Muhammad, "Operation and Maintenance of Hydraulic Structures," in *Hydraulic Structures - Theory and Applications*, 2020. doi: 10.5772/intechopen.91949.
- [17] X. H. Zhang and J. X. Zhang, "Research on disassembling equipment for construction machinery hydraulic cylinder," in *Advanced Materials Research*, 2014. doi: 10.4028/www.scientific.net/AMR.989-994.3323.
- [18] E. D'Aloia, "Hydraulics in the building industry. Moveable structure for casting crossed-beam sections.," *OLEODIN. PNEUM.*, vol. 21, no. 12, Dec. 1980, 1980.
- [19] F. L. Wang, S. Yan, and S. Zhang, "Disassembly energy analysis of the engineering hydraulic cylinder," *Chinese Journal of Engineering Design*, vol. 23, no. 3, 2016, doi: 10.3785/j.issn.1006-754X.2016.03.001.
- [20] M. A. Mansor, A. Ohsato, and S. Sulaiman, "Knowledge Management for Maintenance Activities in the Manufacturing Sector," *International Journal of Automotive and Mechanical Engineering*, vol. 5, no. 1, pp. 612–621, 2012, doi: 10.15282/IJAME.5.2012.7.0048.
- [21] "7463 Pin Spanner Tools for Hydraulic Cylinders On Tractor Loaders Car Auto Parts Nut Wrench Adjustable Gland Nut Wrench - AliExpress." Accessed: Jul. 09, 2025. [Online]. Available: <https://id.aliexpress.com/i/1005005931771087.html>
- [22] "Excavator Bulldozer Repair Wrench Cylinder Tools: Tool To Open Hydraulic Cylinder - Buy Hydraulic Cylinder Repair Wrench tool To Open Hydraulic Cylinder cylinder Tools Product on Alibaba.com." Accessed: Jul. 09, 2025. [Online]. Available: <https://indonesian.alibaba.com/product-detail/excavator-bulldozer-repair-wrench-cylinder-tools-1600262083002.html>
- [23] W. W. De Graaf and W. Spiteri, "A preliminary qualitative evaluation of a hydraulic splitting cylinder for breaking rock in deep-level mining," *J South Afr Inst Min Metall*, vol. 118, no. 8, 2018, doi: 10.17159/2411-9717/2018/v118n8a13.
- [24] T. Li, J. Wang, K. Zhang, and C. Zhang, "Mechanical analysis of the structure of longwall mining hydraulic support," *Sci Prog*, vol. 103, no. 3, 2020, doi: 10.1177/0036850420936479.
- [25] W. Sochacki and M. Bold, "Transverse and longitudinal damped vibrations of hydraulic cylinder in a mining prop," *Vibrations in Physical Systems*, vol. 27, 2016.
- [26] P. Dymarski, C. Dymarski, and P. Grymajło, "An Innovative Method of Measuring the Extension of the Piston Rod in Hydraulic Cylinders, Especially Large Ones Used in the Shipbuilding and Offshore Industry," *Polish Maritime Research*, vol. 29, no. 3, 2022, doi: 10.2478/pomr-2022-0035.
- [27] M. Ashby, *Materials selection in mechanical design: Fourth edition*, vol. 9780080952239. 2010.
- [28] Z. Bi and X. Wang, *Computer aided design and manufacturing*. 2020. doi: 10.1002/9781119667889.
- [29] G. Pahl, W. Beitz, J. Feldhusen, and K. H. Grote, *Engineering design: A systematic approach*. 2007. doi: 10.1007/978-1-84628-319-2.



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