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Research Article

SEMI-AUTOMATIC SYSTEM FOR SETUP PROCESS OF FORGING MACHINE

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ABSTRACT:
Forging is one of the important techniques for bulk metal deformation processes for producing high-strength parts. Metal workpieces are inserted into the cavity between die pieces to form particular shape. The workpiece can be produced with a short cycle time with a hydraulic press. However, the setup process for forging machines takes time due to numerous complicated steps. In this research, a semi-automatic system is developed to improve the machine setup process in regard to positioning of large dies and components. Toyota Production System (TPS) is used to improve the process. The system consists of movable carts integrated with sensors and actuators in order to facilitate the operation. In this case, the prototype system can reduce the setup time by 65% and the operators can work more safely and effectively.

Keywords: *Machine setup, Forging, Semi-automatic, Toyota Production System*

1. INTRODUCTION

1.1 Forging Processes and Machine Setup

Forging is a traditional technique for bulk material deformation processing. However, this technique is used to make a variety of high-strength workpieces these days. A large hydraulic press machine is generally used to generate impact force on a metal billet which is inserted in the cavity between an upper and a lower dies [1, 2]. As a result, the workpiece will be formed according to the shape of the cavity between the dies. The workpiece can be produced with the impact force in a short cycle time.

Before starting forging, the hydraulic press machine needs to be set up to prepare for the desired operations. *"Machine setup"* is a preparation process for the system – e.g. workstation, machine, and operator - in order to complete the work [3]. Machine setup process should be optimized since it is directly related to the time and production cost. Especially for the small lot size batch production, the setup process is required between batches. Therefore, the complicated setup process that consists of a number of steps can eventually result in time consumption which is considered waste.

1.2 Machine Setup Optimization with SMED System

To optimize the setup process, one of the most notable methods is *Single Minute Exchange of Dies* (SMED) which is developed by S. Shingo (1985) [4]. This method is one of the lean manufacturing methods that is used to analyze

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the steps and eventually reduce the setup time [5]. From the study of Shingo [4] on a number of cases, the machine setup activities can be categorized into 4 groups:

- Preparation, after process adjustments, checking of materials, tools and etc. (30%);
- Mounting and removing blades, tools, parts etc. (5%);
- Measurements, settings, calibrations (15%); and,
- Trial runs and adjustments (50%)

The percentage of each activity represents the time consumption which can be varied according to the types and complexity of machines and equipment. To reduce the setup time, the concept is to categorize these activities into 2 types, which are *Internal Setup (IED)* and *External setup (OED)*. The IED are the setup operations that can be performed only when the machine is stopped, e.g. mounting and removing dies. On the other hand, the OED can be performed while the machine is running, e.g. moving the dies from the storage to the machine. The key idea is to convert IED to OED as much as possible and improve the operations to reduce time waste.

1.3 Review of Die and Mold Changing Technology

After process steps have been optimized, the tools assisting the operators to work more effectively and safely are necessary for the improvement. Research works and commercial solutions are available:

In Kosmek Dies Change System [6], an upper and lower dies are transferred by using a table lift. The clamps are operated automatically. The dies are attached before being slid manually on a roller rail to transfer in and out of the press machine. Therefore, the position of the dies cannot be controlled precisely. Bule *et. al.* (2017) [7] also work with automatic clamping system. The clamping system is controlled by using hydraulic resulting in safe and quick die changing.

From Dimeco, [8] The quick die change system has a table lift as a mobile platform that can be moved away from the machine. However, the disadvantage is the limited size and weight of the dies. [9] Rotobloc PSP Die changing system uses a fork lift with an arm for pushing and pulling the dies. The system is a tool, so that the operator still needs to adjust the die position manually.

In summary, from the review of literature, we focus on four issues that take into account to improve the current machine setup of the company. The issues consists of (a) *mobility of the platform*, (b) *weight limitation*, (c) *positioning method of the dies*, and (d) *level of automation*.

1.4 Problem overview

In this article, the dies changing system is implemented in a brass manufacturing company. The workpieces are components of 80 mm ball valves (models: MB80 and BV80) forged by using a hydraulic press machine, ENOMOTO 700GFH. The upper and the lower dies need changing when the models have changed. Currently, the machine setup process takes 90 -120 minutes with 2 operators.

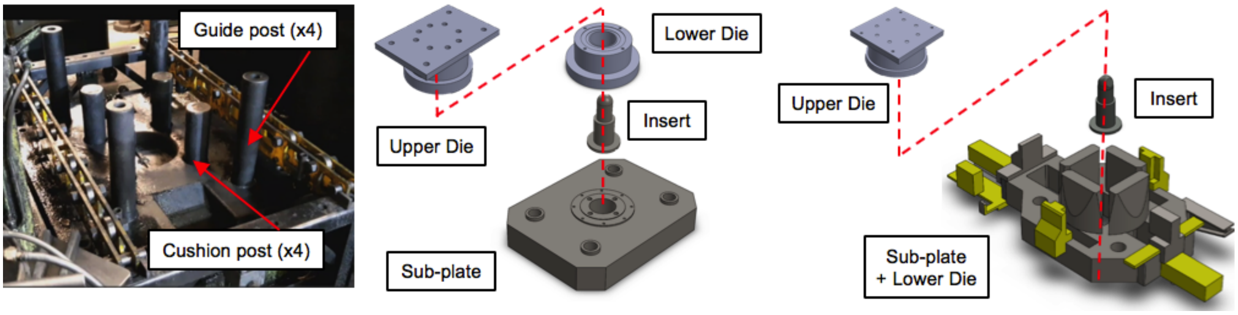
Special tools are designed in this research to optimize the machine setup time. A semi-automatic system is developed to facilitate the IED and OED operations that have been already optimized with SMED and TPS. The process can be achieved more effectively, less labor-intensive, and more safety.

This article is organized as follows. After the reviews of literature and current machine setup techniques in *Section 1*, improvement as a result of work study are explained in *Section 2*. The system design is in *Section 3*, The experiment is *Section 4* and conclusion in *Section 5*.

2. WORK STUDY AND PROCESS IMPROVEMENT

2.1 Components of the current system

For MB80 and BV80, 3 pieces of dies – i.e. *upper die*, *lower die*, and *insert* – are used to produce the workpiece. To be noted that the insert (see Fig. 1b, c) will not be focused in this paper. (a) The upper die is attached with the upper plate which is mounted on the ram. (b) The lower die is mounted on the sub-plate which is mounted on the base. On the sub-plate, there are 4 holes for the guide posts and 4 holes for the cushion posts, where all the posts are on the base (see Fig. 1a). These posts are to align the sub-plate and lower die (see Table 1 for the specification of the components).



(a) Cushion and guide posts (b) BV80 (c) MB80

Fig. 1. Components in the machine and dies set

Table 1: Specification of dies

Component Name	Dimension W x L x H (mm)	Weight (kg)	Tolerance between guide pose and holes (mm)
Upper die MB80	330 x 490 x 329	380	n/a
Lower die MB80 + sub-plate	700 x 905 x 295	700	± 0.4
Upper die BV80	600 x 600 x 306	500	n/a
Lower die BV80 + sub-plate	910 x 1921 x 430	1100	± 7

The machine setup in this case is to exchange the dies between two models. (a) First, to *remove the upper die*, the upper die will be lifted up by lifting the ram. The screws connected between the die and the ram will be detached. The upper die is taken out of the machine. (b) Next, to *remove the lower die*, the sub-plate and the lower die are connected and will be removed together. The screws connected between the sup-plate and the posts will be detached. The sub-plate will be lifted up over the posts and taken out of the machine. (c) Now the dies have been successfully removed. Afterward, the new dies will be installed, in which the process is a reversal.

The entire process looks simple but it does not due to the size and weight of the components. The operations are difficult and inefficient because: (a) all heavy components are transferred between the machines and the storage area by using a factory crane; (b) the hydraulic press is misused to lift all components while staying in the machine; (c) hand tools are used in most of operations instead of power tools; (d) most of the activities depends on skills of individual operators, etc. These issues will be improved by implementing TPS and semi-automatic system that is developed in this research.

2.2 Process Improvement

The original process consists of 55 steps performed by 2 operators. Average setup time for changing MB80→BV80 is 86.55 mins and BV80→MB80 is 67.47 mins (see Appendix). After analyzing with TPS principle, the improvement can be done in 3 categories: *Tools (T), Work (W),* and *Location (L).* The methods which are implemented are listed as follows (see TPS code of the company [10]).

- ***T1*** to use power tool, i.e. air impact wrench, to quickly screw and unscrew the fasteners at the poses, sub-plate, and the dies. The time can be reduced for the related IED;
- ***T2*** to prepare all the tools nearby the machine to improve the logistics in which the traveling time, workload, and movement risk of the operators can be reduced for the related IED;
- ***T4*** to use stoppers to help positioning components, especially for the dies and sub-plate when transferring between carts and machine. Hardware and software stoppers with proximity sensors are used for manual and automatic operations. The time for IED can be improved.
- ***T6*** to design special tools without on-site calibration required. The developed carts are dedicated to the related components of MB80 and BV80 models. The calibration processes are OED;
- ***T9*** to clean and inspect dies. All of these operations are converted to OED;
- ***W1*** to convert IED to OED according to SMED (see Section 1.2);
- ***W2*** to reordering operations to improve IED. The unnecessary work is also removed;
- ***W5*** to reduce walking distance of the operators. This improvement affects IED;
- ***L1*** to relocate the dies to proper locations to optimize the travel paths. This improves IED; and
- ***L2*** to relocate the tools to proper location. This improves IED.

According to the skills set, in this case, the skills set needed for the operators is similar to the machine tools technicians. The skill levels primarily refer to 3 areas that the operators can handle; including, (a) the positioning precision, (b) physical load, and (c) requirement of collaborative works. For example, how precise the operators can move the heavy object to the desired position; how the operators can collaborate with others to complete the task.

3. SYSTEM DESIGN

3.1 Semi-automatic Dies Changing System

This system is to facilitate the operators to transfer and position the dies. The system consists of *carts* and a *lifting platform* contributed to *T2*, *T4,* and *T6*. See Fig. 2 for the system overview.

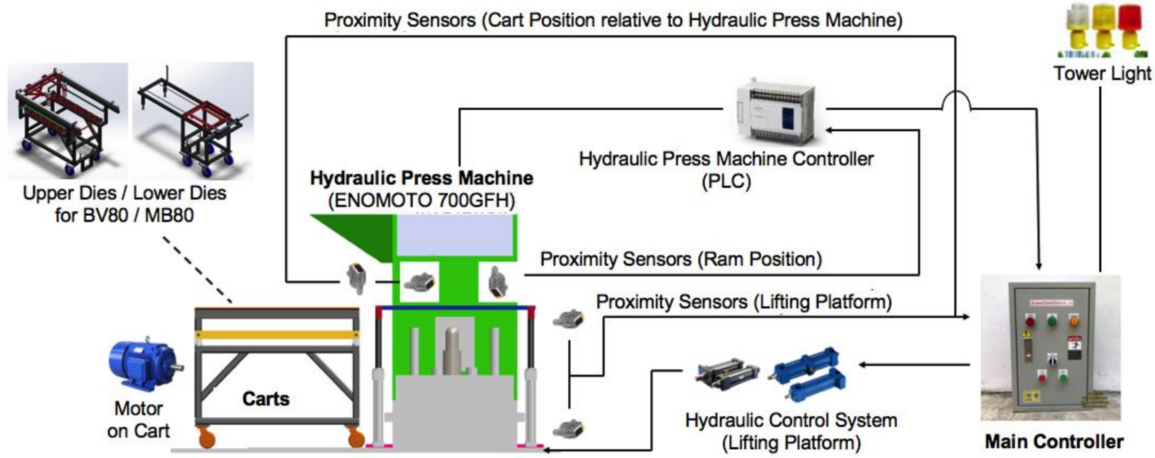


Fig. 2. System diagram of the semi-automatic dies changing system.

(a) *The carts* are portable platforms equipped with sensors and actuators (see Fig. 3a-b). Each cart is designed specifically for dies. The cart has linear guide rails where the dies and the sub-plate can be slid into and out of the machine. With proximity sensors and motors, the dies and the sub-plate can be positioned precisely in the machine. The carts are designed based on specification in Table 1.

(b) *The lifting platform* is used to support the dies and the sub-plate while passing over the posts in the machine. The platform will move down when the sub-plate or the dies are completely aligned with the guide posts. The platform is driven by 4 hydraulic cylinders (⌀50 mm, 300 mm stroke, 15.7 KN 80 bar). Proximity sensors are used for controlling the vertical displacement (see Fig. 3c).

In the process, the manual operations are to move the carts to the working position and to screw/ unscrew (improvement *T1*). The system can be operated automatically by using a Programmable Logic Control (PLC) which link to the carts, the lifting platform, and the hydraulic press machine.

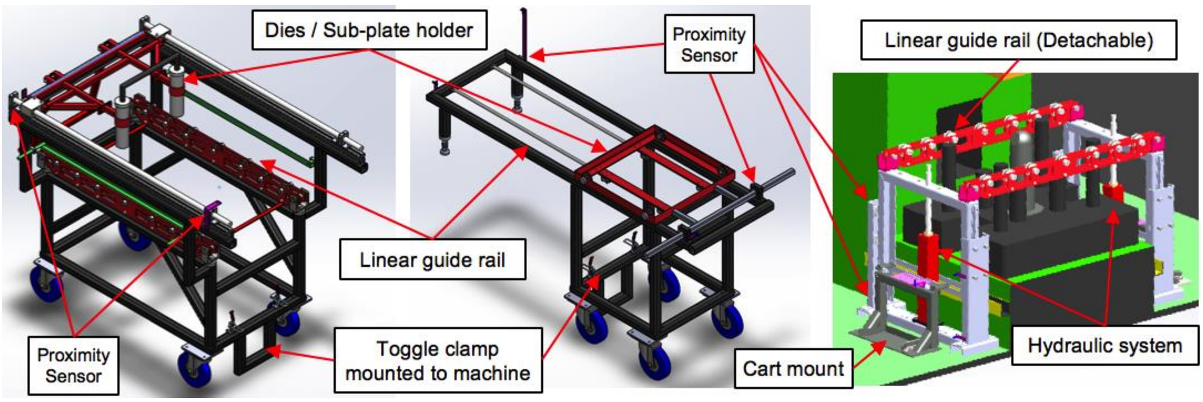
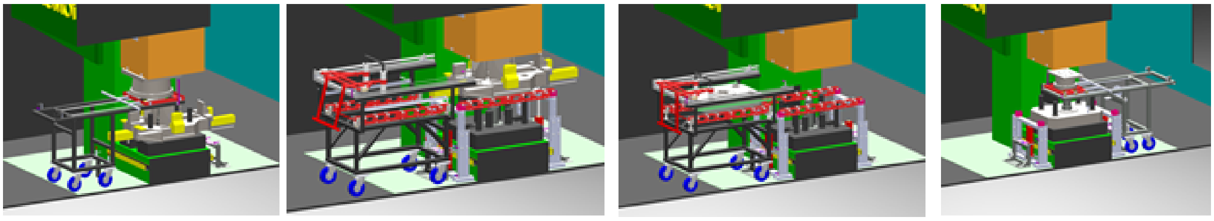


Fig. 3. Mechanical system (a) Cart for lower die (b) Cart for upper die (c) Lifting platform.

3.2 Operation Workflow

Ideally, the cart for the removing the current die and the cart carrying the new die are placed on the opposite sites of the machine. As a result, no extra time for substituting the carts for being at the same location is required (improvement with *W5, L1, and L2*). However, due to space limitation of the shop floor, the carts cannot be organized as proposed. In addition, the lifting platform cannot be installed permanently as it obstructs the upper dies. In summary, the workflow is as follows (see Fig. 4):

(a) Cart for upper die moves in → Jog ram down → Unscrew → Take the current upper die;
(b) Cart for lower die moves in → Install lifting platform → Unscrew at the posts → Platform lifts the lower die to the same level of the linear guides and over the posts → Take the current lower die;
(c) Cart for new lower die moves in → Slide the new die in the machine → Move the lifting platform down and ensure the alignment with the posts → Screw to fix the position; and,
(d) Cart for new upper die moves in → Ensure the alignment of the upper die and the ram → Screw to fix the position → Jog ram up.



(a) (b) (c) (d)

Fig. 4. Workflow of changeover process (changing BV80 to MV80).

4. EXPERIMENT

The experiments are to evaluate the new machine setup process according to the time, the number of operation steps, and risk level. The experiments were conducted on the shop floor (see Fig. 5) by 2 operators.

For the preliminary experiments, the system were tested 2 times where the average setup time were 33.36 mins and 34.45 mins with 56 operation steps. The operators were unfamiliar with the new system during the preliminary experiments. After the new system had been installed for a few weeks, the operators had a chance to practice and get used to it. Consequently, the result was much improved significantly. As a result, the improvement reduced the setup time (MB→BV) from 86.55 mins to 23.12 mins and (BV→MB) 67.47 mins to 24.23 mins (see detailed operations in Appendix). The time improvement was around 70% on average (see Table 2). It should be noted that the time may varies according to the skills of operators.

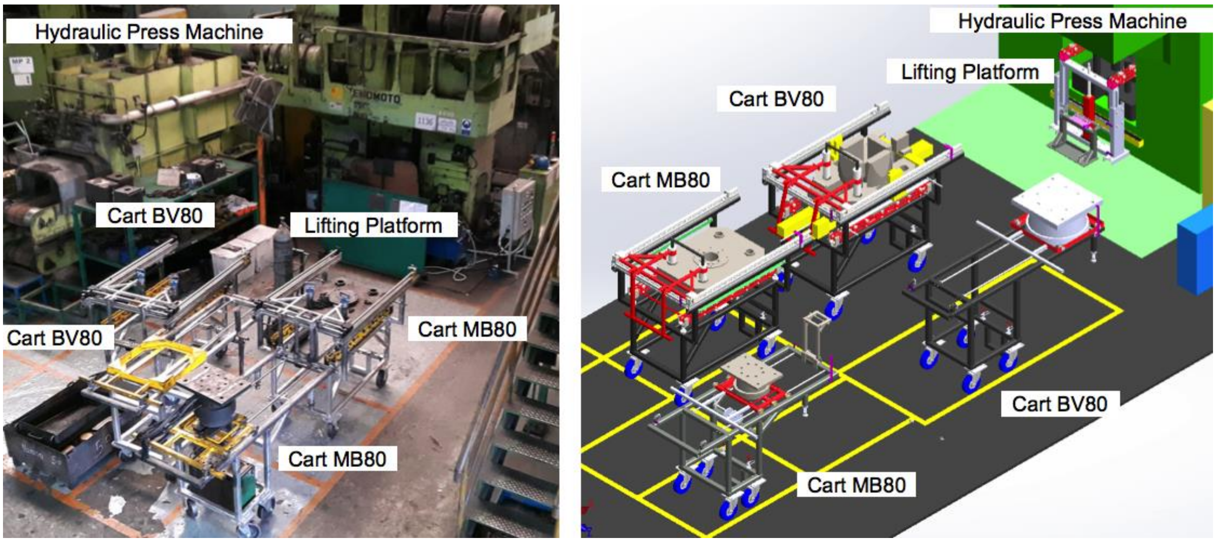


Fig. 5. Comparison between 3D model and the actual system on shop floor.

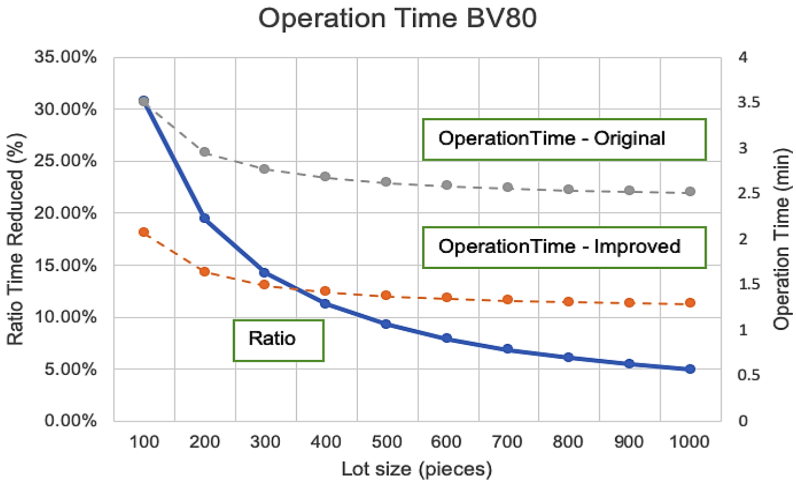
Table 2: Summary of Performance.

System Version	Complexity of task	Skill level	Risk level	No. Operation steps		Time (mins)	
				MB→BV	BV→MB	MB→BV	BV→MB
Original	High	High	High	55	55	86.55	67.47
Improved	Low	Low	Low	54	54	23.12 ([a] 73.27%)	24.23 ([a] 64.08%)

Note: [a] percent of setup time reduced from the original version

The average production rate of MB80 and BV80 is approximately 1,000 items/month for each model, where the principle operation time per items is 72 secs. Average lot size of each model is 160 items. The operation time with the original setup are 1.74 mins and 1.62 mins. The *operation time* is calculated based on *principle operation time* and setup time according to Eq. 1. Therefore, the reduction of setup time significantly improves the operation time especially when the *lot size* is small. The trends of operation time with lot size 100 – 1,000 are shown in Fig. 6. In summary, after the improvement, the operation time are 1.34 mins and 1.35 mins which are around 16% - 23% improvement as shown in Table 3.

Operation Time = (Principle Operation Time) + (Setup Time / Lot size) Eq. 1



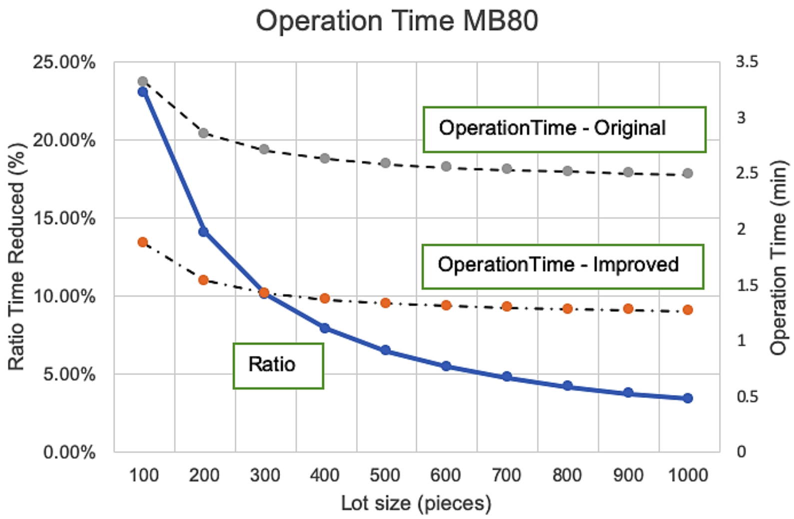


Fig. 6. Operation time reduction (a) BV80 (b) MB80

Table 3: Summary of operation time reduction.

Model	Setup time (mins)		Operation Time (mins)		Ratio Time Reduced (%)
	Original	Improved	Original	Improved	
BV80	86.55	23.12	1.74	1.34	22.77%
MB80	67.47	24.23	1.62	1.35	16.67%

Lot size = 160 items and Principle operation time 1.2 mins/ item

5. CONCLUSION

Exchanging dies is one of the critical procedure in machine setup for forging process. However, it generally takes time and efforts to carry out especially for the operation dealing with large and heavy components. In this research, the setup process is improved by applying SMED and TPS to optimize the operations. Afterwards, a semi-automatic system for die changing, i.e. carts and lifting platform, is developed to facilitate the operations. As a result, the number of operation steps remaining the same but simpler and low skill level needed. The setup time reduced about 65% from 1.5 hrs to less than 30 mins per an exchange process. According to the operation time, the reduction of setup time contributes to around 20% reduction of the operation time for the lot size of 160 items. The production cost is reduced accordingly. However, as the overall production cost consists of many factors, the operation time affects only labor cost and machine operating cost which are only part of overall cost. Detailed investigation is required for cost analysis which will be in the future work.

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APPENDIX

Table 4: Example operations in original and improved version of MB80 → BV80

Original Version				Improved Version				Improvement									
Step	Operation	Tool	Time (mins)	Step	Operation	Tool	Time (mins)	T1	T2	T4	T6	T9	W1	W2	W5	L1	L2
1	Unscrew lower die x4	WR	2.00	1	Unscrew guide post x2	WR	0.15		•					•			•
2	Jog ram down		0.05	2	Jog ram down to sub-plate		0.10										
3	Unscrew guide posts x2	WR	0.12	3	Screw guide post x2	WR	0.15		•					•			•
4	Jog ram up		0.05	4	Jog ram up		0.10										
5	Detach lower die		3.00	5	Move upper die cart in		0.15		•		•				•	•	
6	Unscrew upper die x4	WR	1.20	6	Lock toggle clamp		0.02				•						
7	Jog ram down		0.10	7	Jog ram down		0.10			•	•						
8	Detach upper die		2.30	8	Unscrew upper die holder x4	AW	4.10	•	•								•
9	Jog ram up		0.10	9	Detach upper die		0.05				•						
10	Unscrew upper die holder x4	WR	3.40	10	Unlock toggle clamp		0.02				•						
11	Jog ram down to sub-plate		0.10	11	Move upper die cart out		0.15				•				•		
12	Unscrew upper die holder x4	WR	4.10	12	Unscrew guide post x2	WR	0.15	•	•					•			•
13	Detach upper die holder		0.10	13	Setup lifting platform		3.00		•		•				•	•	
14	Attach eyebolts ram/sub-plate		4.20	14	Move lower die cart in		0.15		•		•				•	•	
15	Jog ram down		0.10	15	Lock toggle clamp		0.02				•						
16	Mount C-support		0.20	16	Lifting platform up		0.10				•						
17	Jog ram up		0.10	17	Detach lower die		0.05				•			•			
18	Setup guide rail		2.00	18	Unlock toggle clamp		0.02				•						
19	Jog ram up		0.03	19	Move lower die cart out		0.15				•				•		
20	Slide sub-plate out		4.00	20	Unscrew insert x4	AW	1.13	•	•								•
21	Drain Nitrogen out		15.00	21	Mount support tool for insert		0.20				•						
22	Unscrew insert x4	WR	1.13	22	Move upper die cart in		0.15		•		•				•	•	
23	Detach insert		0.25	23	Lock toggle clamp		0.02				•						
24	Install new insert		0.30	24	Lift insert up		0.15				•						
25	Screw insert x4	WR	1.30	25	Unlock toggle clamp		0.02		•						•	•	
26	Slide new sub-plate in		9.00	26	Move upper die cart out		0.20			•	•				•		
27	Attach eyebolts ram/sub-plate		2.12	27	Move new upper die cart in		0.20		•		•				•	•	
28	Fill Nitrogen in		0.25	28	Lock toggle clamp		0.02				•						
29	Jog ram up		1.12	29	Place new insert down		0.15				•						
30	Detach guide rails		0.10	30	Unlock toggle clamp		0.02				•				•		
31	Jog ram down		4.30	31	Move upper die cart out		0.15				•				•		
32	Unmount C-support		1.00	32	Screw insert x4	AW	1.30	•	•								•
33	Jog ram up		0.05	33	Move new lower die cart in		0.15		•		•				•	•	
34	Drain Nitrogen out		3.30	34	Lock toggle clamp		0.02				•						
35	Mount upper die support	CR	1.47	35	Mount new upper die		0.10			•	•			•			
36	Transfer upper die to rails	CR	0.30	36	Lifting platform down		0.10				•						
37	Screw guide posts	WR	1.21	37	Unlock toggle clamp		0.02				•						
38	Install guide rails		0.27	38	Move new lower die cart out		0.15				•				•		
39	Slide upper new upper die in		0.19	39	Unmount lifting platform		3.00			•	•						
40	Insert T-Nut on ram		0.30	40	Jog ram down to sub-plate		0.10										
41	Jog ram down		0.10	41	Screw guide post x2	WR	0.15	•	•		•						•
42	Screw upper die x2	WR	0.35	42	Move new upper die cart in		0.15		•		•				•	•	
43	Jog ram down		0.10	43	Lock toggle clamp		0.02			•	•						
44	Screw upper die x2	WR	4.58	44	Unmount lifting platform		0.10										
45	Jog ram up		0.03	45	Jog ram down		0.10										
46	Move cart out		0.05	46	Screw new upper die x4	WR	2.00	•	•					•			•
47	Unscrew guide posts	WR	0.10	47	Jog ram up		0.05										
48	Screw new upper die	WR	1.16	48	Unlock toggle clamp		0.02				•						
49	Detach eyebolts		1.58	49	Move new upper die cart out		0.15				•				•		
50	Fill Nitrogen in		0.39	50	Unscrew guide post x2	WR	0.15		•		•						•
51	Screw guide posts	WR	0.30	51	Jog ram down to sub-plate		0.15										
52	Align upper and lower dies		0.26	52	Screw guide post x2	WR	0.15		•		•						•
53	Jog ram down		0.14	53	Screw new upper die x4	AW	0.20	•	•								•
54	Check upper die screws		0.10	54	Jog ram up		0.10										
55	Jog ram up		0.10														
	TOTAL		86.55				23.12										

Note: Tools abbreviation: "WR" = wrench; "CR" = crane; "AW" = Air impact wrench