Auto Bending Machine Innovation to Improve PCB Production Control Unit

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***ABSTRACT**: This research aims to implement the Auto Bending Lead Capacitor PCB Control Unit machine in manufacturing processes to improve operational efficiency and production capacity. The study begins with a literature review on the use of bending machines in various manufacturing industries, including integration with polarity inspection using Keyence Fiber Optic sensors. The implementation of this machine is based on kaizen and improvement initiatives for continuous improvement in production efficiency, waste reduction, and product quality enhancement. The findings show significant increases in production capacity with a time efficiency improvement of 2.87 seconds per product and monthly cost savings of Rp. 11,671,647. The Break Event Point (BEP) analysis indicates that the initial machine investment can be recouped within 2.7 months post-implementation. Recommendations for improvement include adding distance sensors for bend result detection and integrating production monitoring systems to enhance overall operational control. This research contributes significantly to improving manufacturing process efficiency through cutting-edge technology in electronic component production.*

***KEYWORDS:** Bending Lead Capacitor PCBControl Unit,Kaizen and improvement initiatives, Break Event Point (BEP).*

I. INTRODUCTION

Companies must continue to innovate to remain competitive and meet customer satisfaction.[1]-[2]-[3]-[4]. High quality products provide competitive advantage, while low quality products damage customer trust,[3]. To improve quality, a kaizen approach is needed.[5]-[6]-[7] or continuous improvement, which includes improving production processes, product quality, reducing operational costs,[8] reducing waste, and increasing job security. One important effort is to automate previously manual production systems,[9]-[10]-[11]. The process of bending the electrolytic capacitor legs can be changed from using a conventional bending jig to an automatic bending machine,[12] In addition, the polarity checking and bending processes can be combined into one auto bending machine.

The fundamental problem that needs to be addressed is the quality of the NG capacitor product that exploded during the Final CU process on February 6, 2020 at 21.12 WIB. The results of the investigation showed that the cause was the reverse installation of the capacitor. Human error in operation or programming often causes defective products,[13]. Human error in machine setup and maintenance also increases the number of defective products, such as polarity errors or inaccurate bending. As a result, instead of reducing failed production, the number of substandard products increases. Customer confidence in product quality decreases, and operational costs increase. This process results in more failed products, slows production times, and significantly reduces production output.

Studyshows that the use of various bending machines can increase productivity and reduce failures in the manufacture of capacitors, kitchen appliances, and structural components. Studies on portable roll bending machines,[14] rotary bending machines, and simple lever-based bending tools have shown improvements in small-scale metal bending processes and other component production. Integration of the bending process with polarity inspection using Keyence Fiber Optic sensors has also been identified as an innovative and effective method, although it has not been widely discussed in the literature.

Procurement of Auto Bending Machine [15]-Lead Capacitor PCB Control Unitis part of the kaizen initiative [16] and improvements aimed at increasing efficiency, reducing waste, and improving product quality. Engineering economic studies show that this machine is an absolute necessity, with investments that can provide a quick return or Break Event Point (BEP),[17]-[18]-[19] which is a fundamental financial metric to determine the point at which total costs equal total revenues. Several studies have also shown that BEP analysis [20] effective in improving production processes, as applied to small and medium enterprises, including tofu factories [21] and tea factory [20]. We developed the Auto Bending Lead PCB Capacitor Control Unit machine to increase production capacity and maintain product quality by integrating the process of bending the capacitor electrolytic legs and checking the polarity into one automatic process. This investment is supported by an engineering economic study that shows the absolute need and provides a quick return on investment or BEP.

II. METHODOLOGY

This research method is designed to develop and test the Auto Bending Lead Capacitor CU machine that integrates the process of bending the electrolytic capacitor legs and checking the polarity into one automatic system. The research stages include literature study, system design, machine design, system testing and data analysis.

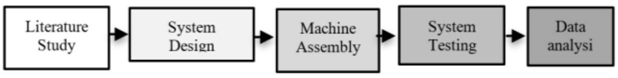


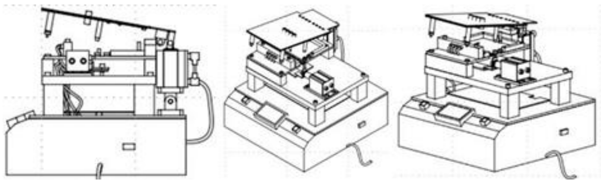
Fig 1. Stages of Research Methods

Fig 1, shows the research stages in realizing kaizen or improvement. Auto Bending Lead Capacitor Control Unit machine that can be explained, namely: first, the research began with a literature study on the use of bending machines to improve productivity and product quality in the manufacturing process, including integration with polarity inspection using Keyence Fiber Optic sensors. The procurement of this machine is part of a kaizen and improvement initiative for operational efficiency and waste reduction, supported by an engineering economic study that shows the need and potential for rapid return on investment. Second, the system design for the Auto Bending Lead Capacitor machine PCB Control Unitincludes major steps such as design using Solid Works, determination of major control components such as Keyence PLC, Keyence HMI, Keyence power supply, and sensors such as Reed Switch, and Fiber Optic sensors. This process also involves the development of HMI with features for process monitoring, production, capacitor polarity, I/O, error logging, and manual operation. Third, the machine assembly process involves the integration of major control components, wiring according to specifications for data communication and sTbl power supply. Input buttons, and buzzers are installed for direct control and notification of operational conditions, ensuring the system operates efficiently and reliably. Fourth, the system testing process includes verification of mechanical components, testing the optimal function of PLC, HMI, and power supply, and sensor accuracy in detecting capacitor position and polarity. This test also involves the automation system and capacitor polarity detection using PLC. Fifth, data analysis is carried out from 30 experiments to evaluate the efficiency of production time and calculate the Break Event Point (BEP) as an indicator of minimum production for the return on investment of the capacitor bending machine.

III. RESULTS AND DISCUSSION

A. SYSTEM DESIGN IMPLEMENTATION

The implementation of the system design involves several important stages such as machine frame design, actuator determination, machine control, and system testing. At this stage, the sensor is tested to ensure that it is able to detect the polarity of the capacitor, regulate the movement of the actuator, and display the final result of the actuator movement.



(a) (b) (c)

Fig 2. Mechanical Design (a) Right Projection, (b) Demetric Projection, (c) Isometric Projection

Fig 2 (a) explains the right projection design, namely the projection of the right side view of the machine. Fig 2 (b) dimetric projection is a projection of the image tilt with two equal angles. This understanding can occur because the dimetric projection contains two axes with the same ratio. Fig 2 (c) isometric projection is a projection that displays objects accurately in the image with the length of the axis that describes the actual size of the object. In isometric projection, the way to display the depiction uses 3 display presentations, namely normal, inverted and horizontal isometric projections. The machine control wiring process involves creating an electrical wiring scheme from control input to load output in a series of machines. This wiring pays attention to aesthetics by providing an address or number on each cable for good identification, as well as the use of different cable colors for AC and DC power sources. The wiring results are shown in Fig 3 (a) and Fig 3 (b).

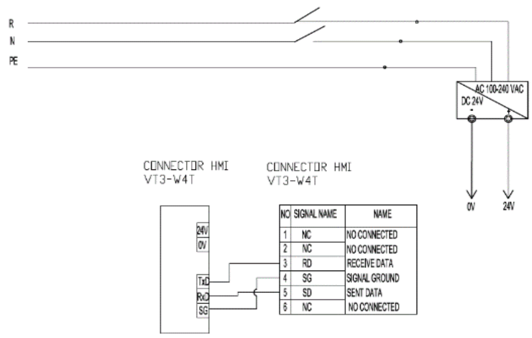


Fig 3. Design Wiring Power 1ØAC100V

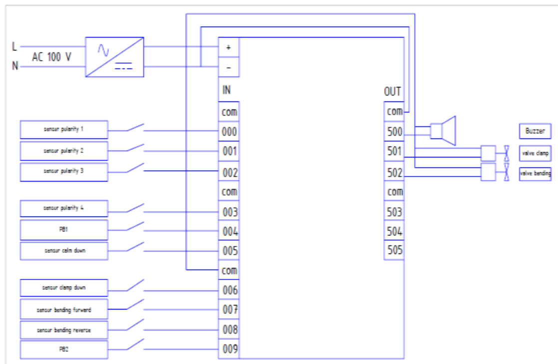


Fig 4. Keyence PLC Wiring

After the wiring and mechanical assembly are completed according to the design, the results can be seen in Fig 5.

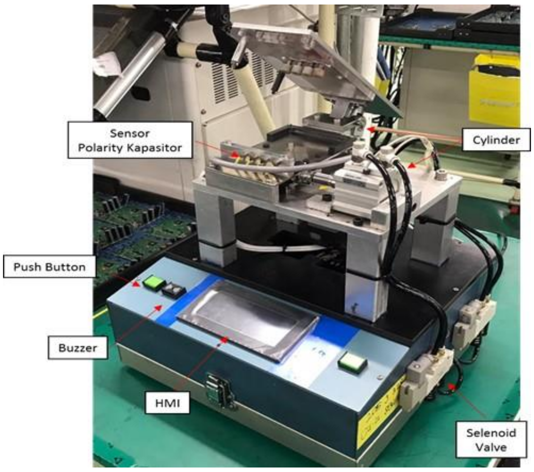


Fig 5. Machine Assembly Result

The process continues with PLC and HMI programming. The PLC programming results are shown in Fig 6.

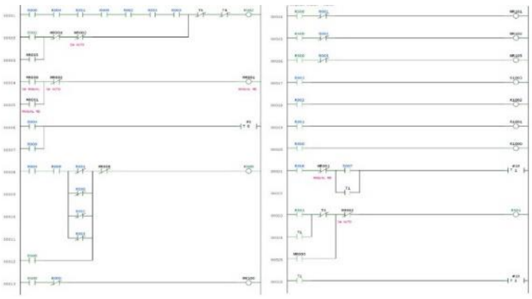


Fig 6. Keyence PLC Program Ladder

Reed Switch The sensor is used to detect the movement of the cylinder on the PCB clamp and the cylinder for bending the capacitor legs. If the cylinder movement is not appropriate, the machine will give an alarm and stop operating.

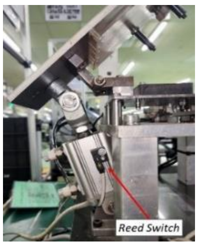


Fig 7. Reed Switch Cylinder Clamp PCB

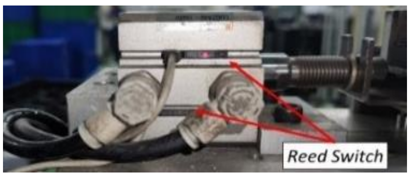


Fig 8. Reed Switch Cylinder Bending

Fig 9. Selenoid Valve

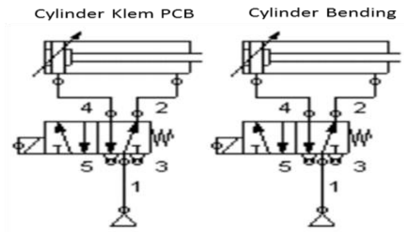


Fig 10. Selenoid Valve Port

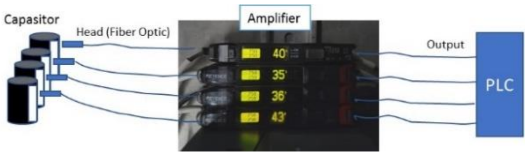


Fig 11. FOS Circuit Simulation

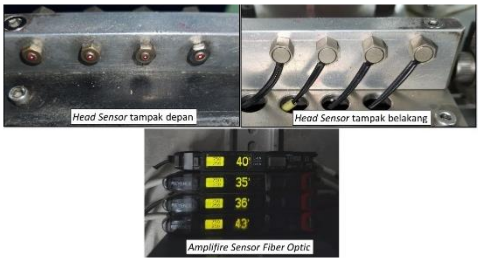


Fig 12. FOS Assembly

HMI facilitate technicians in operating, maintaining, and repairing the machine. The main display and HMI programming results are shown in Fig 13 to Fig 20.

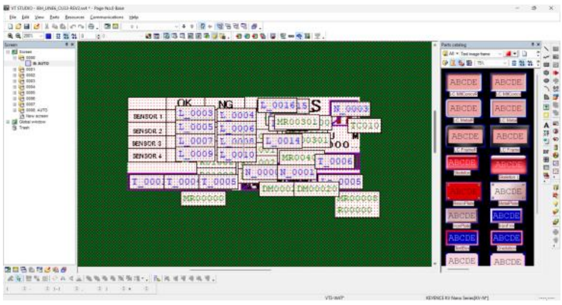


Fig 13. HMI Program Main Screen on Computer

Fig 14. HMI Screen Main Screen

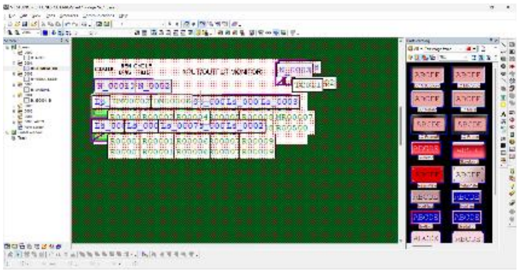


Fig 15. HMI Program I/O Screen on Computer

Fig 16. HMI I/O Screen

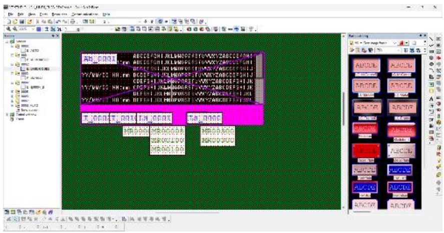


Fig 17. HMI Program Data Logger Error History Screen on Computer

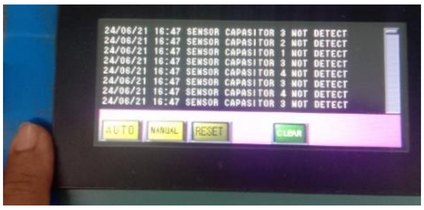


Fig 18. HMI Data Logger Error History Screen

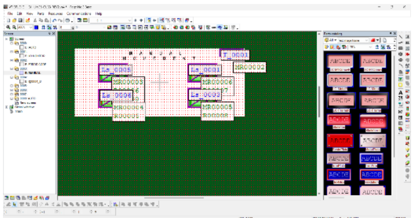


Fig 19. HMI Program Manual Operation Screen on Computer

Fig 20. HMI Manual Operation Screen

B. System Performance Testing

After the design and implementation of the machine is complete, testing of the capacitor leg bending system is carried out. Testing involves several stages:

1) *Production Process with OK Product. The machine operates without any obstacles or failures during the production process. The test results are shown in Tbl 1.*

Tbl 1. Test Result of The Auto Bending Capacitor Machine System Control Unit

From	Product Sensor	Capacitor Sensor	Cylinder Clamp	Cylinder Bending	GO Indicator	Result
Product 1	0	0	0	0	0	OK
Product 2	0	0	0	0	0	OK
Product 3	0	0	0	0	0	OK
Product 4	0	0	0	0	0	OK
Product 5	0	0	0	0	0	OK
Product 6	0	0	0	0	0	OK
Product 7	0	0	0	0	0	OK
Product 8	0	0	0	0	0	OK
Product 9	0	0	0	0	0	OK
Product 10	0	0	0	0	0	OK
Product 11	0	0	0	0	0	OK
Product 12	0	0	0	0	0	OK
Product 13	0	0	0	0	0	OK
Product 14	0	0	0	0	0	OK
Product 15	0	0	0	0	0	OK
Product 16	0	0	0	0	0	OK
Product 17	0	0	0	0	0	OK
Product 18	0	0	0	0	0	OK
Product 19	0	0	0	0	0	OK
Product 20	0	0	0	0	0	OK

From	Product Sensor	Capacitor Sensor	Cylinder Clamp	Cylinder Bending	GO Indicator	Result
Product 21	0	0	0	0	0	OK
Product 22	0	0	0	0	0	OK
Product 23	0	0	0	0	0	OK
Product 24	0	0	0	0	0	OK
Product 25	0	0	0	0	0	OK
Product 26	0	0	0	0	0	OK
Product 27	0	0	0	0	0	OK
Product 28	0	0	0	0	0	OK
Product 29	0	0	0	0	0	OK
Product 30	0	0	0	0	0	OK

Note: 0= The system is functioning properly
1: X = System failure occurred

2) *Level 2 Heading Visual Product Inspection. The product is visually inspected referring to the NG type standard in the Visual Lead Capacitor Manual. The inspection results are shown in Fig 21 to Fig 24 and Tbl 2.*

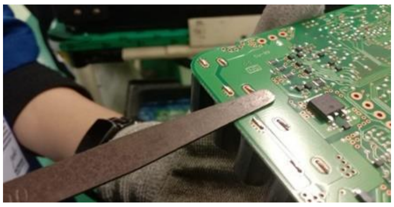


Fig 21. Checking Bending Result Using a 1mm Feeler Gauge

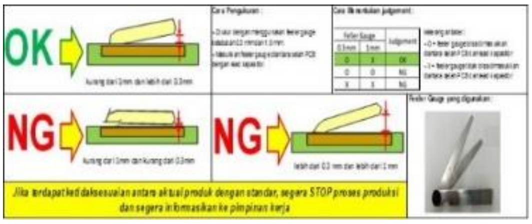


Fig 22. Standard Bending Result

Fig 23. Sise View of Capacitor Bending Result

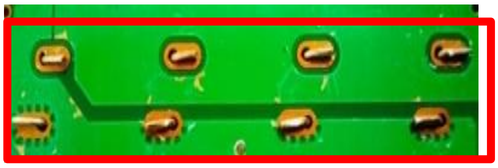


Fig 24. Bottom View of Capacitor

Tbl 2. Experimental Result of Bending Capacitor Legs Using a Feeler Gauge Measuring Tool

	Capacitor 1		Capacitor 2		Capacitor 3		Capacitor 4	
	Feeler Gauge 0.3mm<	***Feeler Gauge <1mm***	***Feeler Gauge 0.3mm<***	***Feeler Gauge <1mm***	***Feeler Gauge 0.3mm<***	***Feeler Gauge <1mm***	***Feeler Gauge 0.3mm<***	***Feeler Gauge <1mm***
Product 1	0	0	0	0	0	0	0	0
Product 2	0	0	0	0	0	0	0	0
Product 3	0	0	0	0	0	0	0	0
Product 4	0	0	0	0	0	0	0	0
Product 5	0	0	0	0	0	0	0	0
Product 6	0	0	0	0	0	0	0	0
Product 7	0	0	0	0	0	0	0	0
Product 8	0	0	0	0	0	0	0	0
Product 9	0	0	0	0	0	0	0	0
Product 10	0	0	0	0	0	0	0	0
Product 11	0	0	0	0	0	0	0	0
Product 12	0	0	0	0	0	0	0	0
Product 13	0	0	0	0	0	0	0	0

	Capacitor 1		Capacitor 2		Capacitor 3		Capacitor 4	
	Feeler Gauge 0.3mm<	***Feeler Gauge <1mm***	***Feeler Gauge 0.3mm<***	***Feeler Gauge <1mm***	***Feeler Gauge 0.3mm<***	***Feeler Gauge <1mm***	***Feeler Gauge 0.3mm<***	***Feeler Gauge <1mm***
Product 14	0	0	0	0	0	0	0	0
Product 15	0	0	0	0	0	0	0	0
Product 16	0	0	0	0	0	0	0	0
Product 17	0	0	0	0	0	0	0	0
Product 18	0	0	0	0	0	0	0	0
Product 19	0	0	0	0	0	0	0	0
Product 20	0	0	0	0	0	0	0	0
Product 21	0	0	0	0	0	0	0	0
Product 22	0	0	0	0	0	0	0	0
Product 23	0	0	0	0	0	0	0	0
Product 24	0	0	0	0	0	0	0	0
Product 25	0	0	0	0	0	0	0	0
Product 26	0	0	0	0	0	0	0	0
Product 27	0	0	0	0	0	0	0	0
Product 28	0	0	0	0	0	0	0	0
Product 29	0	0	0	0	0	0	0	0
Product 30	0	0	0	0	0	0	0	0
Information	0 = Bending result OK X = NG bending result							

3) *Bending process time is measured using a stopwatch. The checking result are shown in Tbl 3.*

Tbl 3. Bending Process Time Check

Test to-	**Time (Second)**	**Test to-**	**Time (Second)**	**Test to-**	**Time (Second)**
1	10.1	11	9.76	21	10.21
2	10.2	12	10.2	22	10.32
3	10.39	13	10.87	23	10.05
4	10.38	14	9.92	24	9.67
5	10.22	15	10.93	25	9.88
6	10.36	16	10.23	26	9.94
7	10.52	17	10.11	27	10.31
8	10.1	18	9.68	28	9.95
9	10.02	19	9.9	29	10.27
10	9.51	20	9.98	30	10.02

4) *Reverse Capacitor Detection. The machine can detect reverse capacitor (NG) and does not operate. The test results are shown in Fig 25 and Fig 26 and Tbl 4.*

Fig 25. Master Sample Polarity Capacitor NG

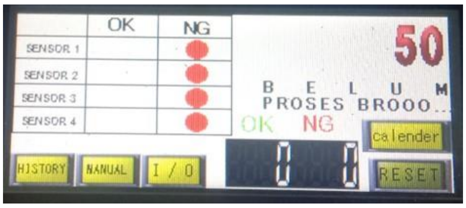


Fig 26. HMI Display NG Indicator

Tbl 4. Bending Process Time Check

	Polarity Capacitor 1	**Polarity Capacitor 2**	**Polarity Capacitor 3**	**Polarity Capacitor 4**	**Result**
Product 1	0	0	0	0	OK
Product 2	0	0	0	0	OK
Product 3	0	0	0	0	OK
Product 4	0	0	0	0	OK
Product 5	0	0	0	0	OK
Product 6	0	0	0	0	OK
Product 7	0	0	0	0	OK
Product 8	0	0	0	0	OK
Product 9	0	0	0	0	OK

	Polarity Capacitor 1	Polarity Capacitor 2	Polarity Capacitor 3	Polarity Capacitor 4	Result
Product 10	0	0	0	0	OK
Note	0 = Capacitor Polarity OK X = Polarity of Capacitor NG				

C. BREAK EVENT POINT (BEP) CALCULATION

BEP calculation is done to determine the break-even point of kaizen investment and the cost efficiency obtained. The calculation steps are as follows:

1) *Time/Process Efficiency: 13 seconds (before kaizen) - 10.13 seconds (after kaizen) = 2.87 seconds/process*

2) *Total Production per Day: 2,400 pcs (estimated)*

3) *Total Working Days per Month: 21 days (estimated)*

4) *Total Time Efficiency per Month: 2.87 seconds/process * 2,400 pcs/day * 21 days/month = 6,888 seconds/month*

5) *Processing Cost per Second: Rp 80.69*

Total Cost Efficiency per Month: Rp 80.69 * 6,888 seconds = Rp 11,671,647

Tbl 5. Bending Process Time Check

No	Name	Qty	Price(@)	Total Price	Caption
1	Mindman Clamp Cylinder SMC MCKB-32M	1pcs	1,430,000	1,430,000	New
2	Mindman Sensor Switch SMC	2pcs	140,000	280,000	New
3	Speed Controller Pisco JSC6-01A	2pcs	98,000	98,000	New
4	AmplifierKeyence FS-N41N	4pcs	12,168,000	12,168,000	New
5	Fiber Optic HeadKeyence FU-35TZ	4pcs	0	0	New
6	Field Lens For Keyence F-3HA	4pcs	0	0	New
7	Keyence VT3-W4T HMI	1pcs	8,000,000	8,000,000	New
8	Switch Power SupplyKeyence	1pcs	936,000	936,000	New
9	PLC Keyence KV-N24DT	1pcs	0	0	New
10	Pisco Tube Ø4	2Mtr	0	0	New
11	Pisco Tube Ø6	2Mtr	4,536,000	4,536,000	New
12	Skun Y 1.25-3	2pack	7,950	15,900	New
13	Control Cable 0.75mm/AWG 24	10Mtr	12,349	24,698	New
14	Marker Tube Putih KSS MT-3	2Mtr	50,000	100,000	New
15	Air RegulatorSMC AR20-02BE-B	1pcs	3,000	30,000	New
16	Solenoid ValveSY5120-5DZ-01F-Q	2pcs	6,000	12,000	New
17	SMC Air Cylinder CDQ2D32-35DMZ-J79W	1pcs	528,000	528,000	New
18	SMC Knuckle I	1pcs	950,000	1,900,000	New
19	SMC Knuckle Y	1pcs	953,500	953,500	New
20	SMC Clevis CQ	1pcs	121,000	121,000	New
21	AC Cord	1pcs	121,000	121,000	Reuse
22	Control Box	1pcs	189,750	189,750	Reuse
23	Frame	1pcs			Reuse
	TOTAL:			**31,443,848**	

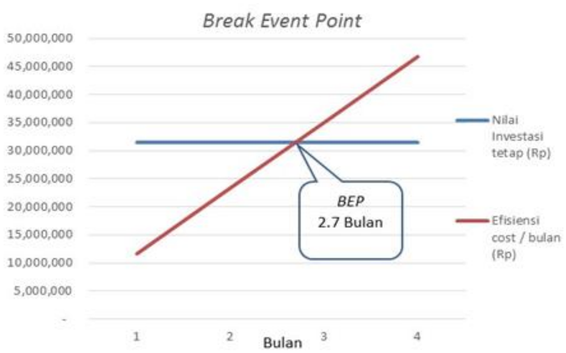


Fig 27. BEP Value Chart

IV. CONCLUSION

This research successfully implemented the Auto Bending Lead Capacitor machine Control Unitto increase production capacity with time efficiency of 2.87 seconds per product and reduce monthly operational costs by Rp11,671,647. With a machine manufacturing cost of Rp31,443,848, Break Event Point (BEP) was achieved in 2.7 months or in the 2nd month, 3rd week after the initial investment. Suggestions from researchers include the addition of distance sensors to detect bending results and the integration of production monitoring systems in the machine to improve operational supervision.

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