Intelligent clutch control with incremental encoder to improve wear issues of an intercept pendulum in real time

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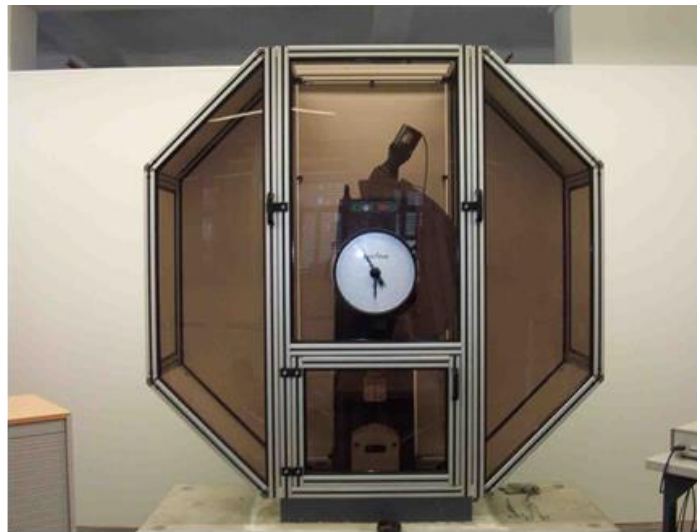[2]Kempten University of Applied Sciences, Faculty of Electrical Engineering, Kempten, Germany

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Abstract. A pendulum impact tester is a technical device which is used to perform plasticity characterizations of metallic materials. Results are calculated based on fracture behavior under pendulum impact loadings according to DIN 50115, DIN 51222/EN 10045. The material is held at the two ends and gets struck in the middle. A mechanical Problem occurs when testing materials with a very high impact toughness. These specimen often do not break when hit by the pendulum. To return the pendulum to its initial position, the operator presses a service button. After a delay of approximately 2 seconds a clutch is activated which connects the arm of the pendulum with an electric motor to return it back upright in start position. At the moment of clutch activation, the pendulum can still swing or bounce with any speed in any direction at any different position. Due to the lack of synchronization between pendulum speed and constant engine speed, the clutch suffers heavy wear of friction. This disadvantage results in considerable service and repair costs for the customer. As a solution to this problem this article presents a customized technical device to significantly increase the lifetime of the clutch. It was accomplished by a precisely controlled activation of the clutch at a point of time when pendulum and motor are at synchronized speed and direction using incremental encoders.
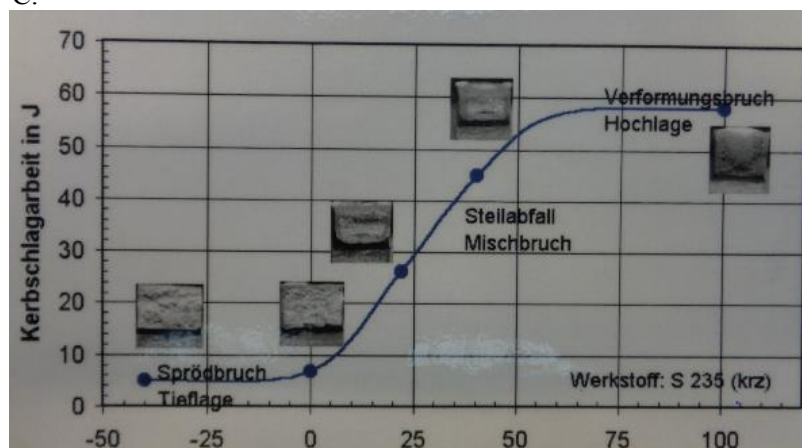
1. Pendulum impact tester
A pendulum impact tester is a technical device which is used to perform plasticity characterizations of metallic materials. [1]
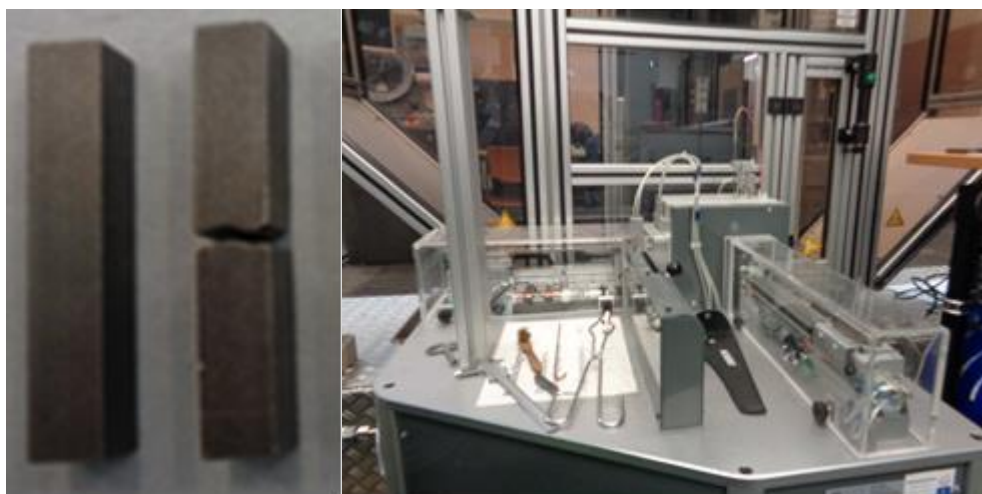
Figure 1. Pendulum impact tester by Zwick/Roell [2]

Results are calculated based on fracture behavior under pendulum impact loadings according to DIN 50115, DIN 51222 / EN 10045 [1], [3], [4]. The specimen testing temperature range is between -190°C and +250°C.

Figure 2. Impact strength as a function of temperature

By Charpy tests the metal is held at the two ends and gets struck in the middle.

Figure 3. Pattern sample before and after the break (left), Clamping device (right)

2. Problems

To return the pendulum to its initial position, the operator presses a service button.

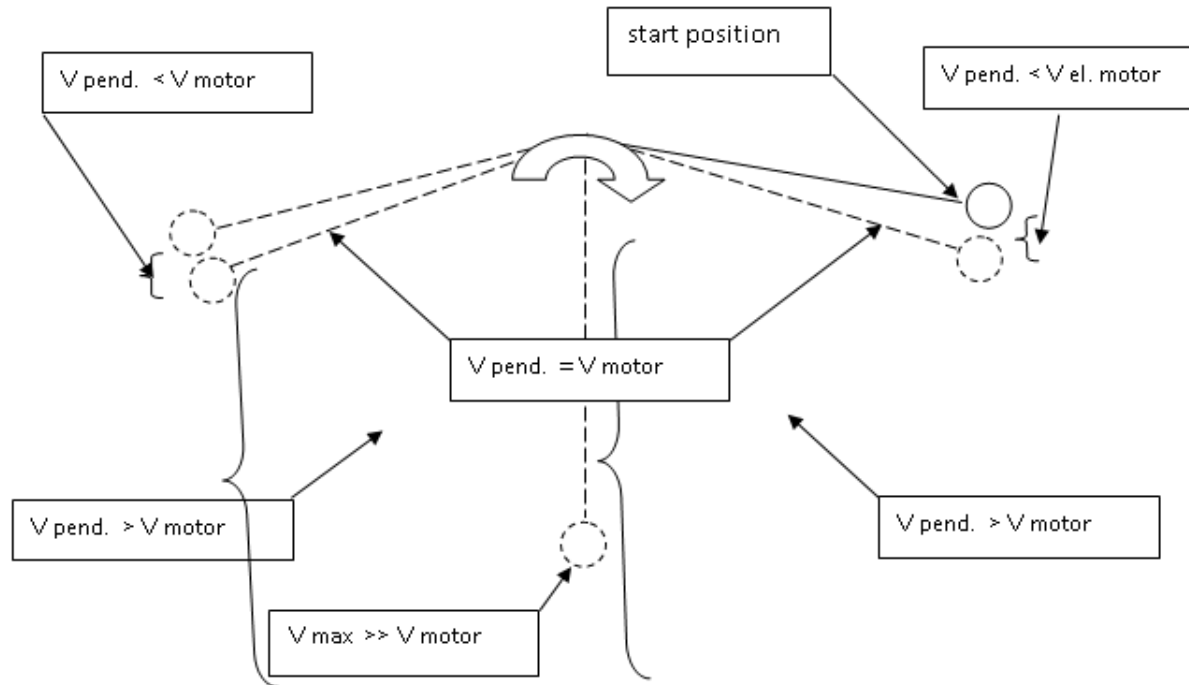**Figure 4.** Control panel with start and service button

After a delay of approximately 2 seconds a clutch is activated which connects the arm of the pendulum with an electric motor to return it back upright in start position.

Figure 5. Electric motor and gear box, Laboratory Hochschule
Ulm, Germany

At the moment of clutch activation, the pendulum can still swing or bounce with any speed in any direction at any different position. Due to the lack of synchronization between pendulum speed and

constant engine speed, the clutch suffers heavy wear of friction. This disadvantage results in considerable service and repair costs for the customer.

Figure 6. Pendulum in motion

A mechanical problem occurs when testing materials with a very high impact toughness are not broken like in the figure below. In this case the pendulum bounces backwards and the clutch suffers excessive wear due to the opposite turning directions between Pendulum and motor. (The clutch is then deteriorated by coming back of the pendulum to the start position.)
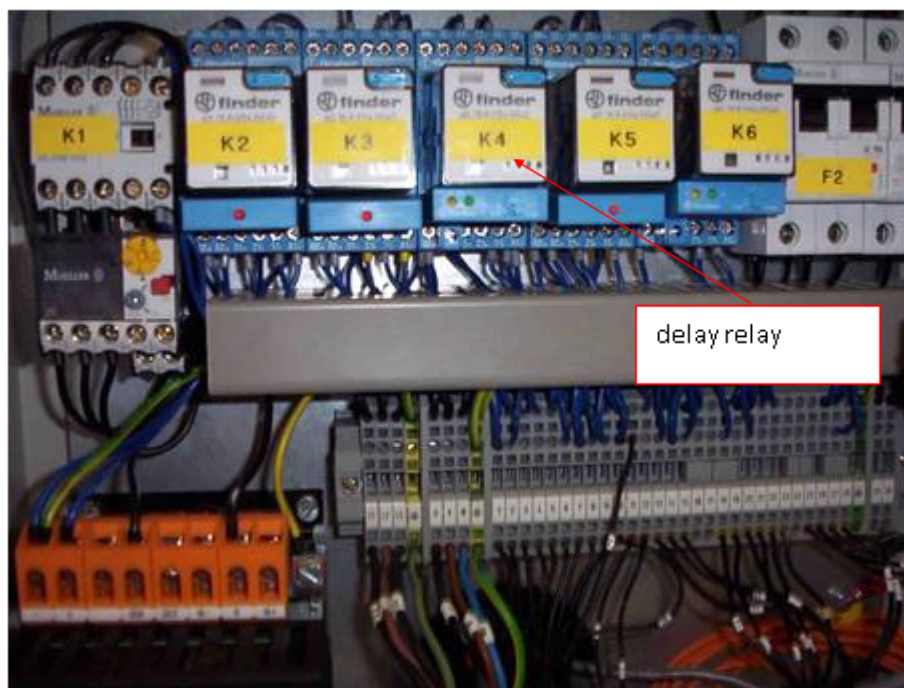
Figure 7. Patterns of tough metal

3. Solution
As a solution to this problem is a customized technical device to significantly increase the lifetime of the clutch. It was accomplished by a precisely controlled activation of the clutch at a point of time when pendulum and motor are at synchronized speed and direction using incremental encoders.

4. Basic requirements
At the time of design of the technical device the following basic requirements had to be considered:

- the device must be designed as an economic retrofit kit,
- must be easy to install,
- it must replace a delay relay,
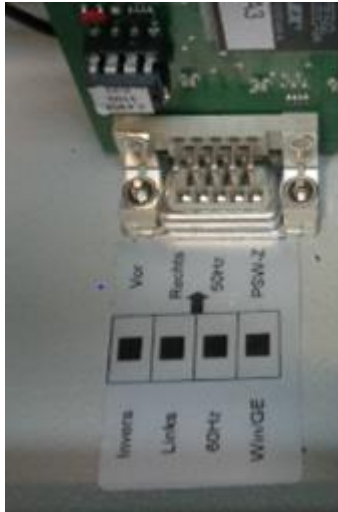- it has to fit in the hitherto existing housing,
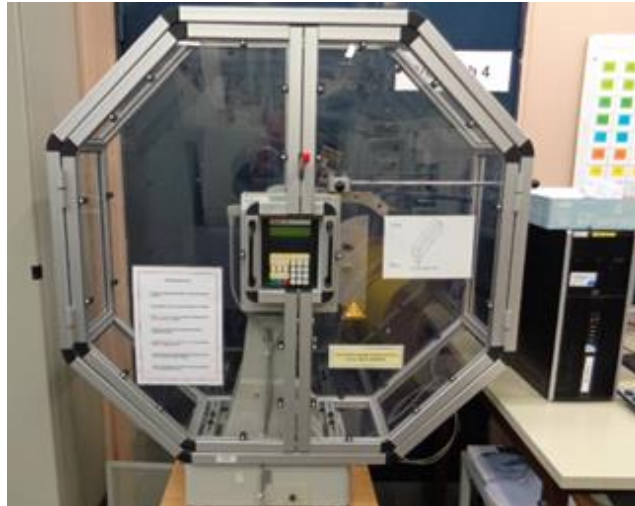

Figure 8. Housing with delay relay

Figure 9. Housing with the new logic unit

- scheduled for 50/60 Hz,
- left or right pendulum locking,
- switching logic for different swing types,
- rugged design

Figure 10. Switching pins   **Figure 11.** A smaller type of an intercept pendulum

5. Preliminary design of the digital circuit

At the design stage of the circuit following problems had to be solved:

- synchronization of the pendulum speed with engine speed when the clutch engages
- selection of hard- and software
- bidirectional evaluation of the pendulum motion
- measurements in real time
- freely programmable circuit

For the control could be selected between the following options: Analog circuits, microprocessors, PLCs, IC – circuits, and EPLD – Blocks.

After trading off the pros and cons, the decision was made for EPLD – Blocks.

To implement the task the development program MAX + plus II was chosen [6]. This software is suitable for both electronics beginners as well as professional developers.
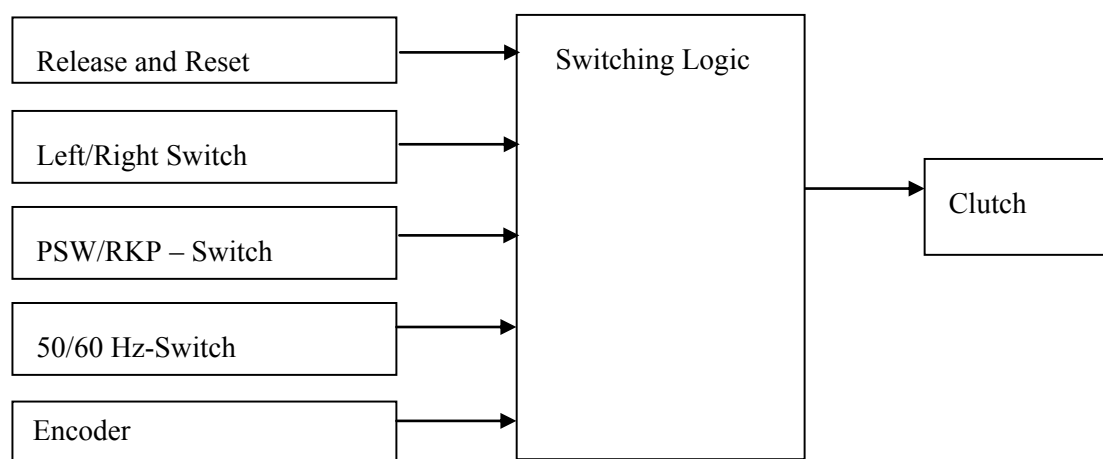
A user friendly interface and the sophisticated digital database allow rapid and sophisticated realization of reliable digital solutions. The programmed digital circuits can be checked for their operability by corresponding simulation surfaces and then transferred to programmable hardware components.

The directional evaluation of the Pendulum motion was solved by using an incremental encoder, placed on the axle of the pendulum. With the incremental encoder, the speed of the pendulum could also be measured.

Figure 12. Digital encoder

These requirements lead to the depicted functional block diagram:

Figure 13. Block Diagram

6. Input data and calculations
The table below shows the key data of the device.

Table 1. Key Data		
Maximal Engine Runtime tmax	160	s
Minimum Engine Runtime tmin	16	s
Number of Encoder Pulses	10000	Pro 360°
Clock Speed	48	MHz
Pendulul Length	0,7	m
Vmax Measured Maximal Speed	5	m/s

6.1. Clock Time:T

$T = 1/f;$ f = frequency

   $T = 1/48\ \text{MHz} \rightarrow T = 20{,}83\ \text{ns}$

   Clock = 20,83 ns at 48 Mhz

6.2. Pendulum Track: U

U is the maximum distance the pendulum can theoretically run during a full rotation.

   U = circumference

   $U = 2\pi * 0{,}7\text{m} = 4{,}4\text{m}$

   Shortest pulse time tmin

   tmin = U : Vmax   Vmax = 5m/s

   tmin = 4,4 m : 5 m/s = 0,88 s

   By 5 m/s and 48 MHz are needed 0,88 s : 20 ns = 42227556 pulses.

   42227556 pulses : 10000 pulses/360° = 4222 clock/pulse

   If the EPLD frequency is reduced from 48 MHz to 3 MHz

   48 MHz : 16 = 3 MHz

   can be measured

   4222 clock/pulse : 16 = 263 clock/pulse.

   This clock frequency is thus sufficient for Vmax . Analog clocks per pulse can be calculated for
other swing speeds.

Table 2. Cycles per pulse at different orbital periods

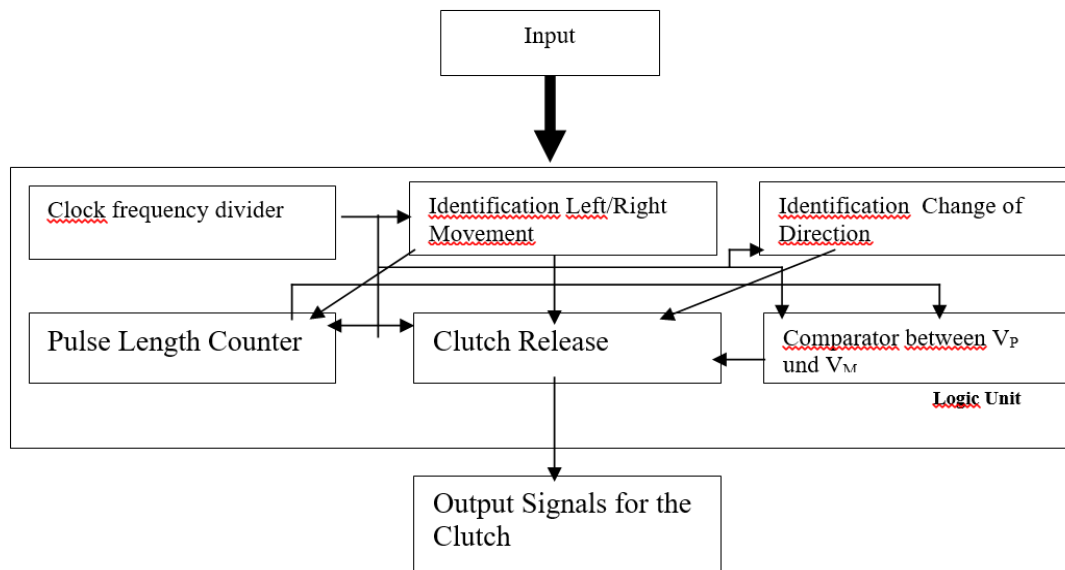| Rotation Time	Clock/Pulse	Clock/Pulse
S	f = 48 MHz	f = 3 MHz
0,88	4223	264
0,90	4321	270
1,00	4801	300
1,10	5281	330
1,20	5761	360
1,30	6241	390
1,40	6721	420
1,50	7201	450
1,60	7681	480
1,70	8161	510
1,80	8641	540
1,90	9121	570
2,00	9602	600
4,00	19203	1200
6,00	28805	1800
8,00	38406	2400
10,00	48008	3000
60,00	288046	18003
120,00	576092	36006
160,00	768123	48008

6.3. Counter bit width

$2x = 48008$ mit x = bit width
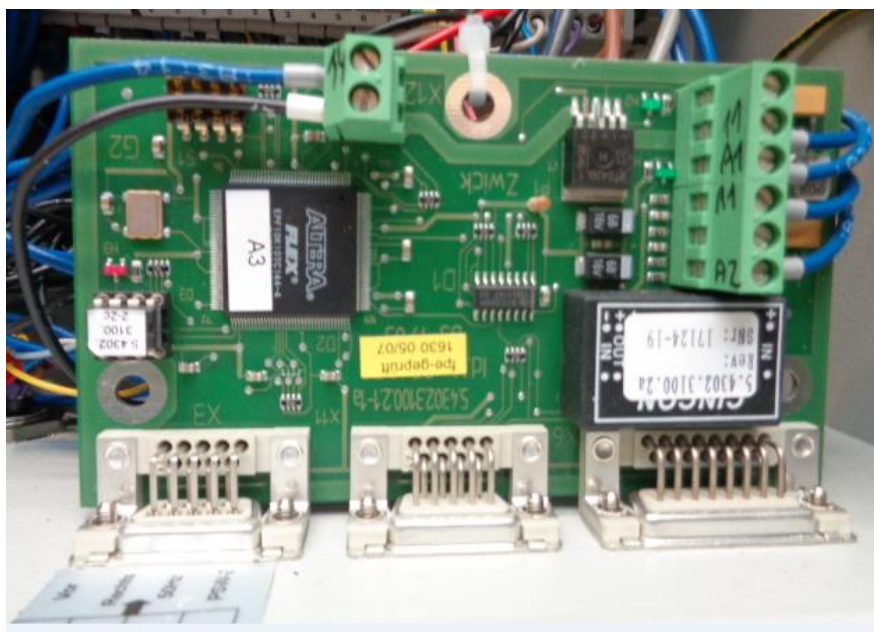
   x = ln 48008 : ln 2

   x = 15,55 ~ 16 bit

   It is therefore a bit width of 16 required. With this bit width both can be detected: very fast and very slow engine rotation speed.

6.4. Logic Unit

The digital logic must include the following function blocks due to the established requirements and the calculation data supplied.

Figure 14. Logic diagram

Figure 15. Logic Unit

7. Conclusion

After the circuit met all the requirements in the experimental stage, it was released for serial production. At this juncture the control unit is installed on both: On new equipment as well as an improvement to earlier devices. It contributes to the increases in sales and to security of employment.

References

[1] *Standards*: DIN EN ISO 148-1:2011-01 (Ersatz für DIN EN 10045-1), (Kerbschlagbiegeversuch); DIN 53 453, DIN 53 753 und DIN 53 448; BS 2782, P.3 Methode 350 und 359; ASTM D 256, Methode A und B; AFNOR NF T51-111;BS 7413; ISO 8256 (Bestimmung der Schlagzugzähigkeit Schlagzugversuch); ASTM D 4812, https://de.wikipedia.org/wiki/Pendelschlagwerk Zwick GmbH & Co. KG, August-Nagel-Str. 11, 89079 Ulm, Germany, https://www.zwick.de/de/aktuelles/news-detail/article/zwick-baut-das-groesste-pendelschlagwerk-der-welt.html

[2] Siebel E 1940 *Handbuch der Werkstoffprüfung*, Erster Band, Springer Verlag Berlin Heidelberg GmbH

[3] Macherauch E and Zoch H W 2014 *Praktikum in Werkstoffkunde*, 12, Auflage, Springer Fachmedien, Wiesbaden

[4] ***Hochschule Ulm*, Prittwitzstraße 10, 89075 Ulm, Germany

[5] ***Altera Corporation*, 101 Innovation Drive, San Jose, CA 95134, USA, https://www.altera.com