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STANDARDIZING PROPORTIONAL, INTEGRAL AND DERIVATIVE PARAMETERS OF BALLOON BLOWING MACHINE IN MANUFACTURING PERCUTANEOUS TRANSLUMINAL CORONARY ANGIOPLASTY MEDICAL BALLOONS

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ABSTRACT

The study emphasizes the crucial standardization of PID parameters - Proportional, Integral, and Derivative to optimize diverse industrial processes. Focusing on balloon manufacturing, particularly in the production of Percutaneous Transluminal Coronary Angioplasty (PTCA) medical balloons, the research centered around into balloon blowing machines. These machines intricately manufacture balloons from heated thermoplastic tubes, emphasizing precise stretching and controlled inflation via nitrogen pressure. Fine-tuning PID parameters within the machine's control system is vital for achieving desired balloon properties. The research systematically explores PID configurations, including P, PI, and PID controllers, tailored for specific process control needs. Through rigorous experimentation, the study identifies optimal combinations of Proportional, Integral, and Derivative parameters. By precisely adjusting these parameters, the research enhances the machine's efficiency, accuracy, and productivity in producing high-quality PTCA balloons. This research not only advances process control knowledge but also holds practical significance for industries reliant on precise manufacturing. The findings provide essential guidance for engineers, researchers, and practitioners in similar setups, illuminating the intricate interplay of PID parameters. Therefore, the present research study elevates understanding in PID parameter standardization, promising heightened efficiency and productivity, particularly in critical fields like medical device manufacturing.

KEYWORDS: *Proportional, Integral and Derivative, Balloon Manufacturing, PTCA Balloons, Process Control and Optimal Configuration*

Article History

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INTRODUCTION

In today's rapidly evolving manufacturing industry, ensuring precise alignment between the set output and the actual output has emerged as a formidable challenge. This discrepancy, often referred to as the 'set vs. actual output,' poses a significant hurdle in maintaining efficiency over time. In the context of this persistent challenge, our research study delves deep into the production process of PTCA (Percutaneous Transluminal Coronary Angioplasty) balloons, focusing specifically on reducing the variation in the B length (total length of the balloon) originating from the balloon blowing machine. The schematic as well as actual depiction of balloon blowing machine is illustrated in **figure 01 & figure 02** respectively.

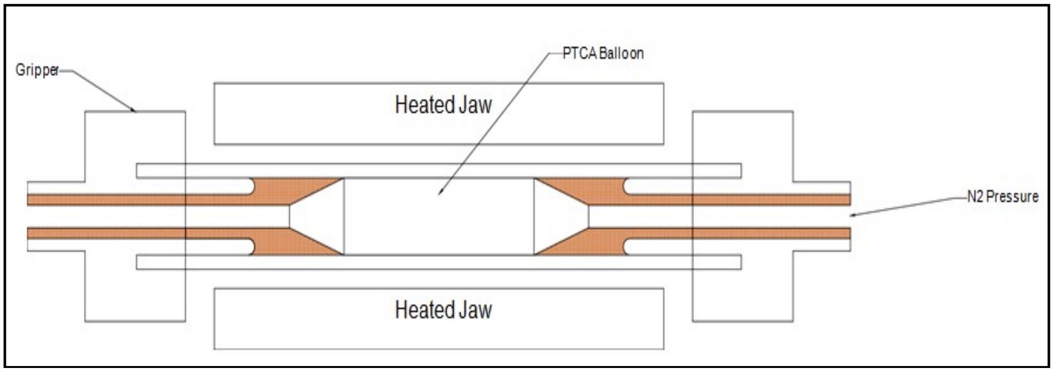

Figure 1: Angioplasty Balloon: Crafted with Precision through Balloon Blowing Process.

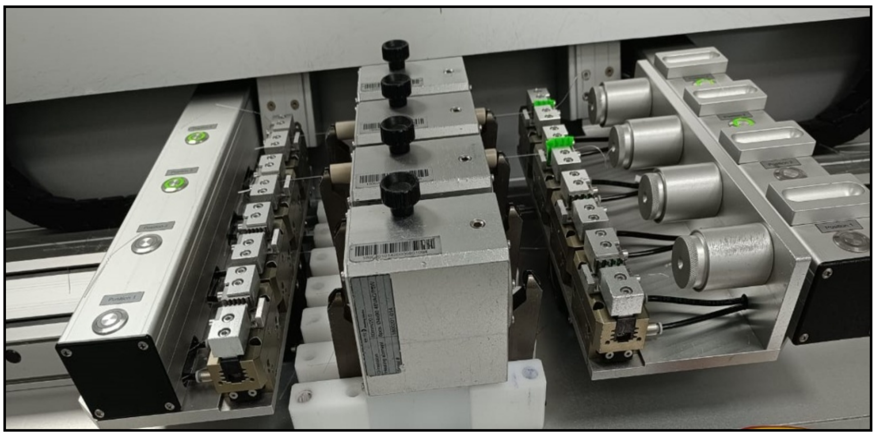

Figure 2: Actual Depiction of Balloon Blowing Machine.

PTCA Balloons, vital components in medical procedures, are crafted from diverse plastic materials. For our investigation, we concentrated a variant of Nylon, Polyethylene terephthalate, Polypropylene etc. rooted in the need to pinpoint the underlying causes of B length variation, we conducted a Why-Why analysis. This survey led us to a vital discovery within the balloon blowing machine temperature irregularities in both Post-1 and Post-2 significantly influenced the B length variation.

Comprehensively dissecting the machine's configuration, we identified six distinct zones across the two posts. In our pursuit to uncover the sources of temperature variation, we employed the rigorous methodology of Design of Experiments (DOE). Through this, we established a direct correlation between balloon B length and temperature. Consequently, the temperature disparities among these zones directly impacted the B length uniformity within the balloons.

To counteract these temperature fluctuations, our research commenced on a series of trials and experiments. Employing a cause and effect (C&E) matrix schematically depicted in **figure 03**, we systematically analyzed the problem, eventually zeroing in on two crucial factors:

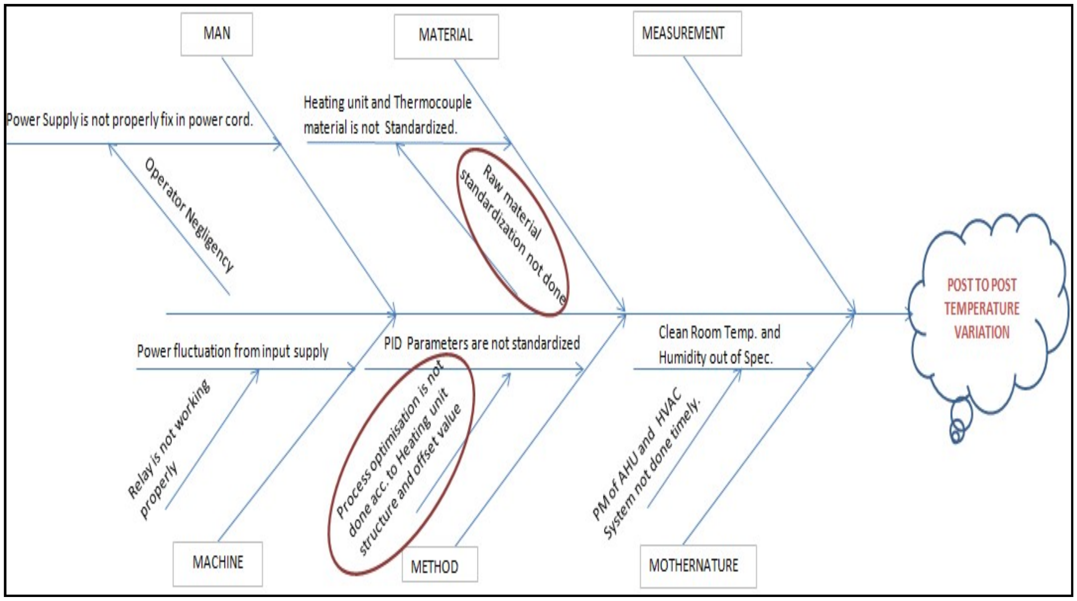

Figure 3: Causes and Effects (C&E) Matrix Analysis.

- **Non-standardization of Heating Unit Design and Material:** The design and material composition of the heating unit emerged as a critical factor contributing to the temperature discrepancies.
- **PID Parameters Misalignment:** The PID (Proportional-Integral-Derivative) parameters, essential for maintaining temperature control, were not aligned with the heating unit structure and its thermal coefficient. These

  Parameters are very critical to reduce the temperature difference between set value and actual value.

In the subsequent sections of this research article, we elaborate on our methodology, findings, and the innovative solutions devised to mitigate these challenges. By addressing these fundamental issues, our study not only enhances the understanding of PTCA balloon production but also contributes valuable insights to the broader landscape of manufacturing processes, paving the way for improved efficiency and precision in industrial production

MATERIALS AND METHOD

PID controllers were traditionally implemented in analog form, utilizing electrical components like resistors, capacitors, and operational amplifiers (op-amps) for control input modulation. The core objective of a PID controller is to dynamically minimize the disparity between a system's output and its desired set point. The procedure is programmed in such a way that the set values and actual values difference get minimized. The processed signal, u(t), is then harnessed to steer the system's output, enabling closed-loop operation. These iterative steps effectively minimize the error and enhance system performance. Refer to the schematic representation in **figure 04** for a visual overview of this PID control approach.

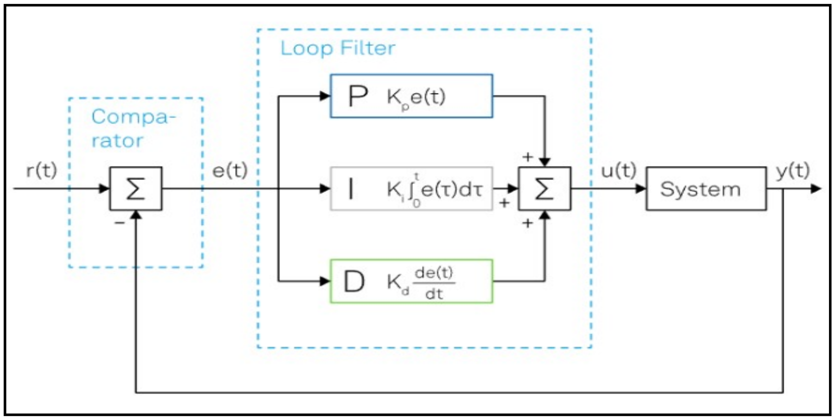

Figure 4: The Schematic Representation for a Visual Overview of PID Control Approach.

The Proportional Term

The proportional term, denoted as P, is a fundamental component in control systems. Its function relies on the discrepancy between the system's actual output and the desired set point. This element facilitates the system's output to return to the set point by making corrections proportionate to the size of the difference. As a result, this process quickens the response time for the correction signal. When the error is significant, the proportional term applies a more substantial correction. To clarify, a larger temperature difference, given a constant Kp (proportional gain), leads to a higher uP(t) output. This implies that even under stable conditions, a slight deviation from the desired set point might still exist.

The Integral Term

The integral term, denoted as 'I' in control systems, is fundamental as it introduces a correction proportional to the accumulated error history over time. Here in the present note, when the difference in desired set point and actual temperature increases beyond acceptable limit is denoted as error in the system. It effectively analyzes the long-term error behavior, offering corrective action that strengthens as the error endures. Unlike its proportional counterpart, the integral term possesses a distinctive capability: it can generate a control signal even when the current error is zero. This unique feature empowers controllers to guide systems meticulously toward the precise desired set point.

With the passage of time, the integral term magnifies, intensifying the correction applied to the system's output. Adjusting the integral gain coefficient amplifies the influence of this accumulated error on the control signal. A higher integral gain coefficient signifies a more substantial contribution of historical error to the control signal, especially valuable in addressing steady-state errors. A substantial integral gain coefficient ensures swift error removal, accelerating the system's convergence to the desired set point.

However, caution is necessary when configuring the integral term. Excessive amplification can lead to "integral windup," a situation where accumulated error causes the control signal to overshoot the set point, triggering oscillations around the desired value. Integral windup destabilizes the system, resulting in erratic behavior and impeding the controller's effectiveness.

In summary, the integral term's ability to consider historical error is pivotal in control systems, enabling precise and efficient regulation of system output. Diligent tuning of the integral gain coefficient is vital, striking a balance between rapid error correction and prevention of integral windup. This ensures the system operates smoothly and accurately.

The Derivative Term

The derivative term, denoted as 'D' in control systems, plays a crucial role in shaping the future behavior of errors. It achieves this by applying a correction proportional to the time derivative of the error, effectively controlling how fast the error is changing. By doing so, it smoothens abrupt shifts in the error, thereby significantly enhancing both the stability and responsiveness of the control loop.

A primary objective of the derivative term is to predict changes in the error signal. If the error shows an upward trend, the derivative action intervenes, compensating even before the error reaches a significant level (similar to proportional action) or persists for an extended period (similar to integral action). This proactive approach ensures that the control system can foresee and counteract potential issues before they escalate.

In practical applications of Proportional-Integral-Derivative (PID) controllers, the derivative action might be omitted due to its sensitivity to the input signal's quality. Rapid changes in the reference value, especially in noisy control signals, can lead to extremely large derivative error values. Such spikes can cause the PID controller to undergo sudden changes, potentially causing instabilities or oscillations in the control loop. To mitigate this, low-pass filtering of the error signal is often employed. However, a delicate balance is essential, as excessive filtering and derivative control can counteract each other, limiting the effectiveness of filtering.

When properly calibrated and when the system demonstrates sufficient tolerance, the derivative action significantly improves controller performance. The influence of each term—proportional, integral, and derivative on the system's behavior is intricately linked to the specific characteristics of the system in question.

To optimize the PID controller's performance and achieve the desired accuracy and responsiveness, engineers and practitioners can adjust the weighting of the proportional (Kp), integral (Ki), and derivative (Kd) gains. This adjustment process allows for precise tuning, ensuring that the PID controller operates with accuracy, stability, and efficiency across diverse real-world scenarios.

RESULTS AND DISCUSSION

In our study aimed at controlling temperature variations in Post1 and Post2, as well as individual zones of the Balloon Blowing Machine, several experiments were conducted. Initially, we found that the thermal conductivity of metals, defining the metal's heat transfer potential, varied significantly due to non-standardized materials and structural dimensions of the heating units. This lack of standardization led to inconsistencies in temperature control, with differences arising from varying materials and assembly methods, especially concerning PID parameters and ramp-up times across different heating zones.

To address these challenges, we took a systematic approach. First, we standardized the material and structural dimensions of all heating unit parts, ensuring consistent assembly. Through numerous trial runs, adjusting PID parameters, we identified optimal settings that minimized temperature variations. Standardizing both materials and designs proved essential for maintaining uniform heating unit performance.

Moreover, we conducted an equivalency study on the heating zones, analyzing the rate of temperature change during the cooling cycle. Surprisingly, variations in pneumatic pressure applied to different zones showed no significant impact on temperature fluctuations, leading to a null hypothesis regarding pressure's role in temperature variation.

Simultaneously, in our investigation of materials similar to Polyamide (Nylon), we delved into its molecular characteristics. We found that the polydispersity index (PDI), representing size distribution in a sample, significantly influenced thermal conductivity. Higher degrees of polymerization (DOP) led to increased thermal conductivity, with a plateau at high DOPs. However, PDI variations did not significantly affect thermal conductivity when average molecular weight remained constant. Additionally, we discovered that the material's mechanical properties were profoundly affected by moisture absorption, highlighting the need for controlled storage conditions.

In summary, our results underscore the principle of critical importance of standardized materials, structural dimensions, and PID parameters in ensuring consistent temperature control. Additionally, understanding the interplay of molecular characteristics, such as DOP and PDI, in materials similar like Nylon , is vital for predicting thermal conductivity. Lastly, the study emphasizes the necessity of controlling moisture content and storage conditions to maintain the mechanical integrity of materials used in PTCA balloon products. These findings provide valuable insights for manufacturing processes, enabling the production of high-quality, reliable products in various industrial applications.

CONCLUSION

In conclusion, this research underscores the significance of standardizing PID parameters such as Proportional value, Integral value, differentiation value, along with heating unit structure. These standardizations ensure consistent temperature control in manufacturing processes. Additionally, it ensures uniform ramp-up times for all heating units, referring to the time taken by individual heating zones to increase the temperature from ambient to the desired set temperature. By establishing constant PID parameters aligned with the standardized heating unit structure and material composition, we have demonstrated a substantial reduction in temperature variations. Moreover, the utilization of low-moisture PA tube material is crucial for ensuring the mechanical integrity of PTCA balloons.

A pivotal insight gleaned from this study is that temperature variations in machinery are not solely attributed to heating unit structure and materials; PID parameter variations also play a significant role. This finding has far-reaching implications across diverse manufacturing sectors where precise temperature control during the production process is imperative. Specifically, the applications of this research are invaluable in the medical sector, notably in machinery such as Balloon Blowing machines, Extrusion process machines, and Injection molding machines. Implementing the knowledge derived from this study stands to enhance the quality and reliability of manufactured products, contributing to advancements in various industries, particularly in the critical realm of medical technology.

REFERENCES

1. *Maxwell James Clerk 1868. On governors, Proc. R. Soc. Lond.16270–283*
2. *Y. Tian and D.P. Atherton. Analysis and Design of Reset Control Systems. Institution of Electrical Engineers, 2004.*
3. *Ziegler, J. G., & Nichols, N. B. (1942). Optimum settings for automatic controllers. Transactions of the ASME, 64(6), 759-768.*
4. *Cohen, H., & Coon, G. A. (1953). A linear operator approach to the analysis of closed-loop servomechanisms. Journal of the Franklin Institute, 256(6), 489-512*

5. *Åström, K. J., & Hägglund, T. (1995). PID controllers: Theory, design, and tuning (2nd ed.). Instrument Society of America.*
6. *Luyben, W. L. (1990). Plantwide control: Some practical considerations. Chemical Engineering Progress, 86(4), 49-53.*
7. *Horng-Yuan Jang et al. Nonlinear optimal on-line heat-dissipation control methodology in electronic devices Int. J. Heat Mass Transfer (2009)*
8. *Wen-long Cheng et al. Studies on thermal properties and thermal control effectiveness of a new shape-stabilized PCM (Phase Change Material) with high thermal conductivity Appl. Therm. Eng. (2012)*
9. *Fan He et al. Thermal management of batteries employing active temperature control and reciprocating cooling flow Int. J. Heat Mass Transfer (2015)*
10. *X. Duan et al. Heat transfer in phase change materials for thermal management of electric vehicle battery modules Int. J. Heat Mass Transfer (2010)*
11. *Lei Cao et al. Properties evaluation and applications of thermal energy storage materials in buildings Renew. Sustain. Energy Rev. (2015)*
12. *Wen-long Cheng et al. New shape-stabilized PCMs with positive temperature coefficient (PTC) effect: preparation and analysis Energy Convers. Manage. (2014)*
13. *Wen-long Cheng et al. Theoretical and experimental studies on thermal control by using a novel PTC material with room temperature Curie point Int. J. Heat Mass Transfer (2014)*
14. *Astrom, Karl J., Hagglund, Tore., "Advanced PID Control", The Instrumentation, Systems and Automation Society.*
15. *Cooper, Douglas J. "Practical Process Control E-Textbook " http://www.controlguru.com*
16. *Scrcek, William Y., Mahoney, Donald P., Young, Brent R. "A Real Time Approach to Process Control", 2nd Edition. John Wiley & Sons, Ltd.*