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Mistake Proofing Cam Mechanism Through Six-sigma Process: Case Study on Clothes Printing Machines

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ABSTRACT

Controlling the occurrence of defects is a major challenge for manufacturing organizations that are seeking to enhance their competitive position in today's global market. This paper considers the process of screen-printing T-shirts using hydraulic and pneumatic printing machines. Several defects in the output of this printing process have been observed, especially with multi colors printing as well as maintenance problems. The six-sigma DMADV approach has been implemented to improve the process performance. Modifications of the current printing machine design using mistake proofing principles that have been proposed to prevent or diminish the occurrence of defects. The analysis indicates that manipulation of wrong oriented products of T-shirts printing machines can be considered as the main effective problem results from machines that are driven by hydraulic or pneumatic systems. Consequently, the quality level and productivity are affected. Moreover, some stained products with leakage fluid from the hydraulic systems can appear. Relying on the DMADV process, an effective mechanical mechanism using Geneva cams was used for diminishing these problems. Geneva cams prototype is manufactured to be used in printing machines instead of the hydraulic or pneumatic systems. A prototype of the cams mechanism is used for testing and validating the presented idea.

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1. INTRODUCTION

Responding to the market hard competitions, organizations always seek to improve their manufacturing processes via the implementation of performance improvement initiatives. Currently, many improvement initiatives are available e.g. lean manufacturing, total quality management, six-sigma, etc. Six Sigma methodology is widely used for enhancing productivity, improving quality and reducing process variation. This methodology determines the root causes of the problems using a detailed analysis [1]. Several approaches can be considered with Six Sigma methodologies. One of these is the define, measure, analyze, design, and validate (DMADV) approach. Since the DMADV mainly aims to design or redesign products or processes; therefore, it is commonly known as design for six-sigma (DFSS). The six-sigma process is widely adopted by practitioners and researchers for manufacturing and service organizations. This process provides a good structural thinking for problem solving and offering the most effective treatment plan. During the implementation of the DMADV methodology, several quality improvement tools can be integrated. Some of these tools in modern factories rely on using proper cost effective techniques such as mistake proofing principle. Mistake proofing is a Japanese concept called Poka-Yoke. Any improvement mechanism or generated idea for avoiding mistakes can be considered as a Poka-Yoke concept or technique in a productivity management process that assists an operator in avoiding mistakes [2]. Moreover, no mistake can happen although any person wants to make it in the working area deliberately or unintentionally through considering the Poka-Yoke concept [3]. This concept has proven to be cost effective in building quality into production processes rather than inspecting and eliminating poor quality. Ideally, Poka-Yokes guarantee that suitable conditions exist before implementing a

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process step for diminishing significant errors from occurring. Poka-Yoke can be applied using simple issues as; sensors, electromechanical stops, warning devices in addition to jigs and fixtures. As introduced in literature [4], Poka-Yoke concept is used for many applications. Mistake proofing can be done by replacing the existing imprecise driving systems with exact one. The mechanical mechanisms are the most precise mechanisms almost used in all machines. One of these mechanisms is the Geneva cams mechanism.

The Geneva cams mechanism is an effective indexing tool. The Geneva cams mechanism converts continuous rotation into discontinuous rotary motion with equally and precise periods of stops. Its rotary drive has pin moving into the slot of driven wheel as presented in literature [5]. Many of the previous works studied the effectiveness of Geneva mechanism as discussed in literature [6], where they increased the efficiency of bottle washing machine.

The current paper proposes the DMADV process as a basis for mistake proofing. Here proofing of mistakes mainly rely on a redesign of a specified part or mechanism in the machine under consideration. The study presents an application case study on screen printing machine of T-shirts. The existing mechanisms depend on pneumatic and hydraulic circuits that produce an imprecise stroke for the printing operations. By using the DMADV process, it is proposed to replace the pneumatic or hydraulic based mechanism with Geneva cams mechanism. The proposed mechanism was validated by simulation and prototyping in order to put it into action and eliminate a set of problems.

2. LITERATURE REVIEW

The DMADV process was adopted for many applications. As an example, it was used to design a new dormitory concept at the University of Miami by Johnson *et al*. [7]. It was used to improve the quality of the surveillance camera by redesigning its PCB [8]. Jiang et al. [9] used it also for designing a silicon microchannel heat sink in order to produce a device with better heat transfer at smaller dimensions. The literature provides many success stories of the implementation of DFSS in production e.g. Samsung SDI, suppliers of white goods in Europe and Ford Company [10]. In automobile manufacturing, one can find many applications that use DFSS for designing or redesigning of vehicle subsystems, e.g. [11] proposed to use the DFSS to satisfy automobile airbag performance by optimizing the composition of airbag covers that produced from thermoplastic polyolefin material. El-Sharkawy et al. [12] used it to design the heat exchanger, afterwards [13] used it for creating a brand powertrain sound for a high-performance vehicle. Formerly, Sethuramalingam et al. [14] used it for developing an automobile cooling system. Moreover, DFSS was integrated with Kaizen for the reduction of oil consumption in diesel engine [15]. Wu et al. [16] proposed to follow DMADV process for producing a high performance and low-cost electric motors for electric vehicles. Jaswal et al. [17] implemented it for the redesign of the vehicle exhaust System. Recently, it was used by Wang [18] to design the intake and exhaust system of a heavy-duty diesel engine. In service sectors, Azis and Osada [19] proposed a DFSS roadmap to manage process innovation in a healthcare organization. Potra and Pugna [20] used DFSS in the design of marketing campaign. For supply chain systems, [21] used DMADV based simulation for optimizing the logistics of the structure components of Boeing 787 using large cargo freighter. Morover, the implementation of six sigma often entails applying a set of analysis tools e.g. -Failure mode and effect analysis [22]. -Pareto analysis [23]. -Cause and effect diagram [23]. -Quality function deployment [20]. -Design of experiments [15]. - Control charts [17]. -Process capability [22]. -Decision tree [23]. -Value stream map [22]. -Fault tree analysis [1]. -Statistical analysis [12]. -and Simulations [9] [14] [16].

Geneva mechanism is the most popular as an indexing mechanism. Furthermore, a design and implementation of Geneva mechanism's digital manufacturing using an integrated CAD-cam virtual prototype are introduced by Stanasel and Blaga [24]. Likewise, Geneva Mechanism with curved slots is designed and analyzed by Hsieh [25]. Some of the previous research work studied the effective usage of Geneva mechanism in different production applications. For example, Sindhur *et al*. [26] controlling a certain machine's cutting feed motion using special mechanism includes Geneva wheel and belt drive. Moreover, the controlled feed motion can be managed through changing the mechanism parameters. Likewise, an improvement of a conventional punching machine is presented in literature [27] using Geneva mechanism.

3. RESEARCH METHODOLOGY

The proposed methodology relies on the DMADV process for improving the special purpose machines. The DMADV comprises five steps: Define, Measure, Analyze, Design and Validate. The define phase is used to highlight the most critical problems of the machine. Those problems include poor quality, low productivity, or low availability. The identification of such problems relies on the associated experts' knowledge. For ranking those problems, the analytical hierarchy process (AHP) is purposed. AHP relies on experts' pairwise evaluation according to a set of predefined criteria. After the identification of the problems, one needs to measure the associated data. This phase is known as “measure phase”. Different data could be measured that includes defect ratio, sigma level, process capability, uptime efficiency, machine yield etc. The data related to the problem should be collected for further analysis. In the case of unavailable production data, experts’ evaluation can be used instead. According to literature [23], mapping cause and effect relation is important to be performed in this phase, in order to gather the related data for the analysis phase. For discovering the root causes of the problems, many tools can be used in the analysis phase. Pareto chart can be used to emphasize the significant problem(s). Ishikawa diagram can be used to analyze the root causes of each problem. For those problems that are associated with the machine in the Ishikawa diagram, we propose to analyze the specified machine to determine the related mechanism(s) or parts that cause the specified problem(s). Mistake proofing action can be proposed by process redesign. In this phase, one can change the technology used, or use the same technology but with different design structure. The proposed design should be verified by mathematical formulation, simulation or prototyping.

4. CASE STUDY

Mistake proofing principles are applied to a T-shirts screen printing machine. Generally, screen printing machines use hydraulic or pneumatic systems attached to a rotary table as indexing and timing arrangement. Generally, screen printing T-shirts process can be considered as a mass production method of the garment by which, an amount of finished garments is printed with the desired design using several types of ink. Screen printing can be defined as forcing an ink process through the mesh of a netting screen stretched on a frame [28]. The production rate of classical screen printing process is faster than the digital textile printers where screen printing rate is around six times of digital textile printer [29]. Screen printing machine contains a set of permeable printing fabrics stretched firmly across the frames. These frames are arranged around the rotatory table as shown in Figure 1. The hydraulic or pneumatic system of screen printing machine controls rotatory table motion. This table has a certain number of frames carrying T-shirts as printing products. Moreover, the rotary table has an indexing motion for giving a certain number of stops during each revolution equals to the number of frames. These stopping and moving periods must be adjusted related to the desired time of printing and swapping between the frames. Hence, new screen printing machines must be provided with increasingly sophisticated controls especially for its rotary table as mentioned in literature [30]. Of course, errors or positional deviations of indexing rotation motion of rotary table result in wrong orientations that lead to produce defected products. Investigating this kind of screen printing process reveals several problems. Furthermore, fluid leakage result in timing fluctuation problems in the indexing system. Hence, this paper is dealing with solving the printing machines problems through the implementation of the DMADV process.

4. 1. Define Phase After investigating the screen printing T-shirts machine, a set of five problems were found. Those problems can be summarized as; P1: represents the depuration of the printer head. This problem affects the quality of the print and causes high defective parts. P2: lack of proper maintenance of the rotational parts. The greatest consequence of this problem is the long downtime that may be extended up to many days. P3: fluid leaks in hydraulic driven system. It produces a high rejection of the final product. P4: placement of the T-shirts on the rotational head. The wrong placement reduces the productivity where it requires the intervention of a worker to correct the placement. P5: locating the head using the proximity sensor. This problem also has quality consequences. In order to discover the impact of these problems a set of four criteria were proposed: C1: production impact "items rejected", C2: health and safety, C3: ease of problem solving, C4: environmental impact. After that a three hierarchy AHP was constructed. The main target is to find the most important problem(s) relying on the evaluation criteria. In order to define the most important problem(s), the production experts are asked to evaluate the different pairwise comparisons. We have five pairwise matrices: evaluations of problems with respect to each criteria (4 matrices) have been constructed. While, the pairwise comparison matrix of the criteria is shown in Tables 1. The evaluation scale used is (1, 3, 5, 7 and 9) corresonding to (very weak, weak, moderate, high, and very high). After the synthesis process of AHP, the different problems were ranked as shown in Figure 2. P2 is the most critical one then comes P3, and P5 that present about 80% of aggregated weight.

4. 2. Measure Phase The data related to the three problems are gathered. For P2: the number of monthly breakdowns of the specified machine was collected, the actions taken to fix the machine was also collected and reviewed. It was observed that this problem takes from one to two days for being solved. For P3: it was observed that this problem produces high noise in work station for pneumatic driven machines. While for hydraulic driven machines the work station is always unclean and this affects the safety of workers. The main cause of this problem is the driving system with its components. Finally, for P5: the data related to the number of malfunction of the proximity sensor was gathered. Also, the number of defective products that produced from this cause was listed.

4. 3. Analyze Phase Based on the collected data, it was clear that the root cause of the most significant problems is the driving and timing system. By investigating these systems, it was found that some machines are pneumatic based systems and others are hydraulic. With excessive discussion with firm experts, all are agreed that replacing such system with mechanical one will solve these problems.

4. 4. Design Phase It was discovered that most of the current machine problems are related to the pneumatic/hydraulic systems. These problems especially wrong oriented products are often owing to fluid leakages, relaying or jamming in cylinders of these systems. Hence, redesigning the pneumatic or hydraulic systems of this machine or replacing it by another mechanism is a good decision. For diminishing most of these problems, an effective mechanical mechanism using Geneva cams was suggested. Geneva cams mechanism components are Geneva wheel and driver disk as shown in Figure 3 with their simple geometry. This mechanism can be considered as a suitable indexing and timing tool that gives a certain rotation motion with a definite period to the current machine rotary table. Then, it stops the rotary table through another definite period. Hence, this stop period affords the required time for the operator in order to do the printing process of T-shirt in a certain frame. Thus, the rotary table moves with a certain period for swapping the frame of the printed T-shirt by another one. Moreover, the number of slots (N) of Geneva wheel plays an important role in producing the required number of stops, which equals to the frames of the T-shirts. Furthermore, the time ratio (T_R) of the moving period to the stop one is an important parameter that must be considered in selecting the dimensions of Geneva mechanism. Figure 3 shows the wheel and driver geometry of the proposed Geneva mechanism. Where; (R) is the driver crank length, (d) is the diameter of the pin and (C) is the distance between two rotations centers of the wheel and the driver. Also; (W), (T) and (L) are the slot dimensions. (R_w and R_d) are the wheel and driver radii. Also, (β and α) are the wheel and driver angular displacements. The stop disk radius of upper cam over driver is (R_1) and (R_2) is the clearance arc radius of the driver, while (R_3) is the stop arc radius of the wheel. The distance between the wheel and pin centers is (B).

Relying on the work reported in literature [5, 24, 31] the main design attributes of the Geneva mechanism can be computed as follows:

$$\mathrm{C} = \mathrm{R}\ \mathrm{cosec}\ \psi, \text{where } \psi = 180^o / N \quad (1)$$

$$\mathrm{B} = \mathrm{R}\sqrt{\frac{1}{\sin^2\psi} - 1} \quad (2)$$

$$\mathrm{R}_W = \sqrt{\frac{\mathrm{d}^2}{4} + \mathrm{R}^2\cot^2\psi} \quad (3)$$

$$\beta = \cos^{-1}\left(\frac{m - \cos\alpha}{\sqrt{1 + m^2 - 2m\cos\alpha}}\right) \quad (4)$$

where: $m = 1/\sin\psi$

$$\alpha = \cos^{-1}\left(m\sin^2\beta + \cos\beta\sqrt{1 - m^2\sin^2\beta}\right) \quad (5)$$

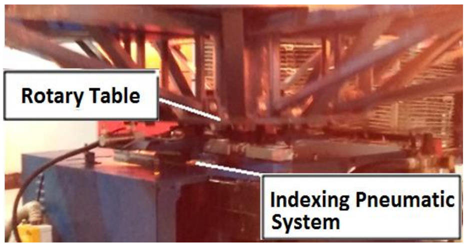

Figure 1. T-Shirts Screen Printing Machine

TABLE 1. Pairwise comparison of criteria

	C1	C2	C3	C4	Ranking
C1	1.00	1.80	0.78	1.80	0.304
C2	0.56	1.00	0.56	1.29	0.192
C3	1.29	1.80	1.00	1.29	0.319
C4	0.56	0.78	0.78	1.00	0.186

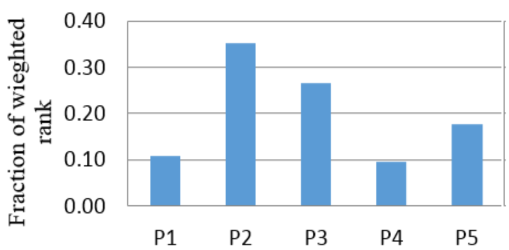

Figure 2. Synthesis results of AHP

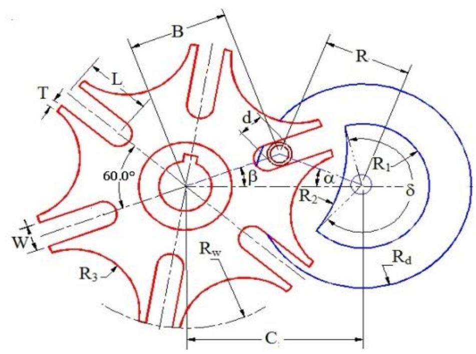

Figure 3. Geometry of the Geneva mechanism

$$T_R = (360^o - \delta)/\delta \quad (6)$$

$$\mathrm{W} = \mathrm{d} + \lambda \text{ and } \mathrm{L} = R + R_W - \mathrm{C} \quad (7)$$

$$R_3 = R - 1.5\mathrm{d}, R_1 = R_3 - \lambda, R_2 = \frac{R_W R_1}{R} \quad (8)$$

Hence; the designer can assume the number of slots (N) related to the required number of the machine frames. In addition to assuming crank length (R) and pin diameter (d). Also, one can assume a working allowed clearance (λ) for calculating the other parameters. The designer can use a suitable comprehensive three dimensional mechanical design and simulation as Autodesk-Inventor Software for testing and animating the suggested mechanism. The suggested Geneva mechanism is shown in Figure 4 which, consists of driver disk, Geneva wheel in addition to a compound cam for giving an up and down motion to the rotary table. Moreover, the bottom end of wheel shaft has roller moving over the compound cam surface of two surface levels.

The previous arrangement provides Geneva wheel with up and down motion that is one of the printing process requests. The Autodesk-Inventor Software is used with an input data; N=6, R=87 mm, d=15 mm, λ=0.2 mm. The calculated dimensions of the mechanism are; $\psi=30^0$, C=174 mm, R_W=150.69 mm, W=15.2 mm, L=63.69 mm, R_3=64.5 mm, R_1=64.3 mm, R_2=111.37 mm and T_R=1:2. Finally, Geneva cams prototype mechanism is manufactured using the previous calculation and the assumed dimensions. This mechanism can be installed in the current T-shirts printing machine instead of the pneumatic or hydraulic systems. Prototype elements; Geneva wheel, cams, and pulley are fabricated using CNC laser cutting from Acrylic material with different thickness. Figure 5 presents the upper and lower parts. The upper one consists of the wheel and driver in addition to supporting frame for generating the desired intermittent motion. While, the lower part consists of a compound cams of two surface levels, bearings and wheel shaft has a roller for generating the desired up and down motion.

4. 5. Validate Phase The presented prototype of Geneva cams mechanism shows that the suggested system is valid to be used instead of hydraulic or pneumatic systems of current T-shirts printing machine. Furthermore, this suggested mechanism works as a reduction gearbox with ratio equals to (1:6). The DT2236B Laser Photo Tachometer is used to measure the input and the output angular velocities of the indexing system. Figure 6 shows the relation between the measured input and output angular velocities in addition to the theoretical ones of the suggested system.

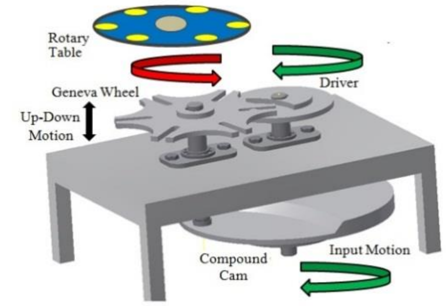

Figure 4. Geneva Mechanism Components

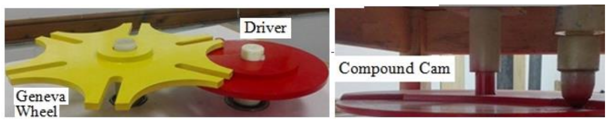

Figure 5. Upper and Lower Parts of Prototye

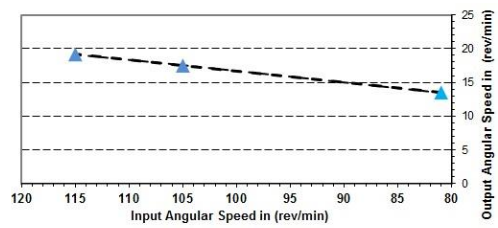

Figure 6. Input and Output Angular Velocities

Furthermore, the measured reduction ratios of the suggested system have a constant rate (1:6) which is similar to the theoretical ones. Also, the time ratio (TR) has a constant value equals to (1:2). The performance achieved from the fabricated prototype is promising and very encouraging to start implementing the proposed design on the real full scale machine. Significant reduction in the defect rates as well as increased productivity are expected to be achieved after implementation on the full scale machine. This is based on the observed superior performance of the prototype. That can be mainly attributed to the accuracy of the mechanical indexing system as opposed to the hydraulic or pneumatic ones.

5. CONCLUSIONS

This paper considers improving the T-shirt printing process through the application of the Six Sigma DMADV approach. Problems associated with a use of pneumatic or hydraulic systems in the printing machines have been investigated and highlighted. After analyzing the most critical problems in this process, it has been suggested that the current printing machine design should be modified. A new design that serves as a mistake proofing design has been proposed to prevent the occurrence of these critical problems. An effective mechanical mechanism using Geneva cams is suggested for eliminating most of the current problems. Usage of this mechanical mechanism is more precise than the pneumatic or hydraulic systems. Moreover, this mechanism can be considered as an effective indexing mechanism with a few moving period's deviations and errors. Finally, Geneva cams prototype mechanism is manufactured to be connected to the current T-shirts printing machine instead of using pneumatic or hydraulic systems. This prototype of cams mechanism is used for testing and validating the proposed design.

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Quality Improvement

چکیده

کنترل وقوع نقایص یک چالش عمده برای سازمان های تولیدی است که در جستجوی بهبود موقعیت رقابتی خود در بازار جهانی امروز هستند. این مقاله روند چاپ تی شرت های چاپی را با استفاده از ماشین های چاپی هیدرولیک و پنوماتیک در نظر می گیرد. چندین نقص در خروجی این فرایند چاپ مشاهده شده است. رویکرد DMADV شش سیگما برای بهبود عملکرد پردازش اجرا شده است. تغییرات طراحی ماشین چاپ کنونی با استفاده از اصول تصحیح اشتباه که برای جلوگیری یا کاهش وقوع نقص پیشنهاد شده است. تجزیه و تحلیل نشان می دهد که دستکاری محصولات غلط چاپ ماشین های تی شرت می تواند به عنوان اصلی ترین مشکل موثر از ماشین آلات که توسط سیستم های هیدرولیک و پنوماتیک هدایت می شود. علاوه بر این، برخی از محصولات رنگ شده با مایع نشت از سیستم های هیدرولیک می توانند ظاهر شوند. با تکیه بر فرایند DMADV، مکانیسم مکانیکی موثر با استفاده از کامپوننت های ژنو برای کاهش این مشکلات استفاده شد. نمونه اولیه کامپوزیت ژنو برای استفاده در ماشین های چاپی به جای سیستم های هیدرولیک یا پنوماتیک تولید می شود. نمونه اولیه مکانیزم کامپوزیت برای آزمایش و اعتبار دادن ایده ارائه شده مورد استفاده قرار می گیرد

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