Abstract

The present habilitation thesis "*Innovative methods in cold plastic deformation processes, in the design of Coordinate Measuring Machines and in the Quality Assurance of parts by three-dimensional measurement*" summarizes the research and academic activities in the field of industrial engineering carried out by the author of this thesis in the period 1999-2022, after the public defense on 26.02.1999 of the PhD thesis entitled "*Study of automatic flexible cold forming lines*".

The work is structured in three main parts, the first being a summary of the author's scientific, academic and professional achievements. The second part details the author's scientific achievements followed in the third part by plans for career development. The habilitation thesis ends with the list of bibliographic references associated with the three parts.

In the first part of the habilitation thesis (**Chapter 1**) the main scientific, academic and professional achievements of the author, obtained in the last 23 years since the public defense of the PhD thesis, are mentioned. The research carried out during these years can be grouped into two main areas: cold plastic deformation manufacturing processes and technologies and three-dimensional measurements. The area of cold plastic forming manufacturing processes and technologies is a continuation of the research in the PhD thesis. The second area, three-dimensional measurements, has been developed since 2000 in two directions: the design and performance verification of Coordinate Measuring Machines (CMMs), and the quality assurance of 3D plastic moulded and printed parts by three-dimensional measurement procedures. In addition to these areas, research can be added in the field of manufacturing engineering such as: plastic injection moulding, ultrasonic activation of various manufacturing processes, superfinishing machining by lapping, machining by chipping etc. Research results are presented in the form of scientific articles, patents, published books and research contracts. From the point of view of academic achievements, the teaching activity carried out during this period of time, the professional training activity and the author's functions and responsibilities at department and faculty level are presented. The professional prestige of the author of this habilitation thesis is validated by the national and international impact of the published books, the results of the contract research and the published scientific papers and the CMM models designed, built and sold in Europe and Japan. In addition to the professional prestige can be added the quality of the member of national and international professional organisations, a reviewer for national and international conferences, and prizes, medals and diplomas won.

The second part (**Chapter 2**) presents the most important results of the author's research. This part has been structured in three sub-chapters as follows.

Chapter 2.1 presents issues related to the automation of cold plastic forming manufacturing processes. Thus, the results of research on the operating regimes of some cold forming manufacturing systems built on single or multiple forming machines were presented. After defining the modes of operation of a flexible automatic cold-pressing line, the research continued with modelling the operation of the control unit of a flexible automatic cold-pressing line. The modelling of the operation of the control unit of the line started from the analysis of the specifications, which should specify the specific functions of the control unit, taking into account its modes of realisation and use. The operation of the line was described by means of functional diagrams (GRAFCET – ”*Graphe Fonctionnnel de Commande Étape Transition”*) that allow to describe all the expected behaviours of the control unit in relation to the totality of events or information coming from the automated process. On the basis of the model obtained through different GRAFCETs, the physical modeling of the control unit was performed by using the electromechanical and pneumatic technology. A particular importance for automatic cold-pressing

lines is the determination of the productive capacity and energy consumption of cold-pressing manufacturing systems, i.e. the improvement of the control operation of a flexible automatic cold-pressing line. Using the Design of Experiments (DoE) and Analysis of Variance (ANOVA) methods, the power consumption on an automatic line was determined and how it was reduced depending on the value of the independent factors (press cadence and press loading). In order to improve the setting operation of an automatic line, the actions of reducing the duration of the setting operation on a flexible automatic cold-pressing line built with classical presses by applying the principles of the S.M.E.D (Single Minute Exchange Die) method were presented. In the second part of this chapter, the results of an experimental investigation on the ”*autofrettage”* parameters of thick-walled tubes are presented. This research was financed by the Reșița Mechanical Plant (UMR), having as its subject the study of the ”*autofrettage”* of artillery tubes. As a result of this research, the values of the ”*autofrettage”* parameters were established, carried out with dorn and deformation ball, in order to obtain a tube with higher strength at the same wall thickness.

Chapter 2.2 deals with issues related to the design and performance verification of Coordinate Measuring Machines (CMM). The first part of sub-chapter 2.2 presents the results of research on the design of a CMM. The research started with a study on the role of CMM in quality assurance. This included the concept of coordinate measuring, factors influencing measurement accuracy and the main coordinate measuring systems. A study on the behaviour of a CMM for high speed and variable thermal field measurements is presented. This study was carried out during the design phase of the CMM with fixed bridge and moving table (Presingo 755). Finite element analysis (FEA) performed with Ansys software was carried out for two different structures of the fixed bridge and moving table CMM. Following this analysis, the dynamic performance of the two structures was determined at different dynamic and thermal stresses of the structures. The research continued with a study on the modular design of a CMM. For this purpose, a modular design solution of the architecture with fixed bridge and moving table was presented, which allows the measuring volume of the machine to be modified, especially in the Z-direction, within certain limits and without major modifications. A modular design of the moving table was also analysed which allows the conversion of the machine from a three-axis to a four-axis machine with an included rotating table (R-axis). The results of the design of the linear drive systems for the upgrade of the TESA MicroMS 343 manual handled CMM were presented. The aim of the research-design activity was to present a technical solution for the modernization of the existing TESA MicroMs 343 manual handled CMM in the 3D Measurement Laboratory of the Politehnica University Timișoara to become a CNC machine. The results of the research on the design of a ”L-shape” bridge CMM based on fundamental design principles: high repeatability (design for repeatability) and high predictability of the machine response to the main sources of error (design for predictability) are presented below. Based on these two principles, the CAD model of the ”L-shape” bridge machine was built and the dynamic error of the virtual model was determined. Finite element analysis (FEA) was used to calculate the total deformation of the mechanical structure and, in particular, the total displacement of the stylus tip caused by the acceleration of the ”L-shape” bridge.

The second part of chapter 2.2 presents the results on the evaluation of the accuracy of CMM with tactile probing system. The accuracy of a CMM is very important to be known in order to obtain quality results when measuring the part. In this regard, a first study on the performance of a manually driven CMM is presented. Thus, the evaluation method and the results on the accuracy (BIAS), repeatability and reproducibility of the TESA MicroMS 343 manually driven CMM were presented. The research continued with several studies on the measurement uncertainty of CMM with reference to the TESA MicroMS 343-CNC. For different configurations and orientations of the resistive touch trigger probe system, the control factors: number of measuring points, rotation angles of the measuring head, measuring planes, probe length, diameter of the probe tip, respectively different modules of the TP20 touch trigger probe, which have an

effect on the measurement uncertainty, were investigated. The Design of Experiments (DoE), Analysis of Variance (ANOVA) and Response Surface Method (RSM) were used to investigate the impact of the factors on the measurement uncertainty. As a result of these experimental studies, conclusions and recommendations on the configuration of the probing system to reduce measurement uncertainty were formulated. One conclusion that emerges is that the measurement result of the workpiece can be influenced by the configuration of the probing system. In this respect, it is recommended to use probes of the smallest length and the largest diameter (high rigidity) and to measure geometrical elements as far as possible with the same probe and the same orientation of the measuring head.

Chapter 2.3 presents more research on quality assurance of 3D printed and plastic injection molded parts using 3D measurement procedures. The first part describes the main directions of three-dimensional part measurement and the suitability or unsuitability of contact or non-contact sensors for measuring parts made of different materials, i.e. of different sizes and accuracies. Several strategies for measuring geometric elements of a plastic injection molded part that may exhibit high dimensional and geometric deviations are also presented. It also describes how to carry out first part inspection for a plastic injection molded part used in the automotive industry and presents the results of the part measurement, i.e. conclusions on the test and production start-up phase with possible changes in injection molding or mold calibration parameters. The second part of the chapter presents the results of research on the influence of technological parameters on the dimensional characteristics of parts made of resins by 3D printing. The 3D printed parts, using digital light control (DLP) technology, were made from ordinary resin and plant resins, called eco-resins. The main objective of the research was to determine how the support structure in the DLP 3D printing process influences the characteristics of flat and cylindrical surfaces. A Coordinate Measuring Machine (CMM) with a contact probe was used to measure the physical characteristics of the printed part. The Design od Experiments (DoE), Analysis of Variance (ANOVA) and Response Surface methods were used to carry out the experimental investigations and to analyse the results. On the basis of the dimensions and geometry of the 3D printed parts obtained from their three-dimensional measurement, the optimal values of the independent factors (supports density, contact depth, contact surface diameter) that have a significant influence on the dimensional and geometric parameters of the 3D printed part were determined. At the same time, the dimensional and geometric deviations of the part were classified into certain accuracy classes of ISO 2768-1 and ISO 2768-2 standards, thus establishing the accuracy class that can be achieved in 3D DLP printing of these parts.

Chapter 3 outlines the author's career development plans. The first direction concerns cold plastic forming manufacturing processes and technologies. The focus will be on the automation and optimisation of manufacturing processes, i.e. the optimal and innovative design of dies. The second direction concerns the study of the suitability and performance of different three-dimensional measuring systems to increase part measurement accuracy. The third direction aims at studying the quality assurance of parts by 3D measurement strategies. It will consider the development of 3D measurement strategies for parts made of different materials and using different manufacturing technologies.

The habilitation thesis ends with the list of bibliographic references associated with the three parts presented in Chapters 1, 2 and 3.

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