Thermal Modelling And Simulation Of Automatic Welding System.

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Abstract

This paper covers the development, design and simulation of an automatic real time control system applied in mechanical system of recovery of spur gears. using modern techniques of automatic welding. This automatic system permits to recover the initial geometric contour of the wheel by performing automatic welding runs across each tooth, keeping the mechanical properties intact.

The thermal model that describes the process of heat transfer in the wheel under the regimen of automatic welding is defined in order to obtain the behavior of the temperature gradient in the entire wheel body. Computer simulation was carried out with experimental data.

The general hardware architecture of the automatic system of recovery of the spur gear is proposed, where robotic and artificial vision systems are used.

Keywords

Automatic Welding,Thermal Modelling,Real Time Systems,and Mechatronic.

1 Introduction

Spur gear is a specific big wheel that can reach up to one ton of weight. Their dimensions and weight can vary from one type to another according to the type of application. They are located in many factories, and it constitutes one of the most important mechanical elements in several technological processes and industries; for example in sugar factories. During the normal operation the wheels are subjected to the effects of compression, crushing (bearing) forces, squashing and severe mechanical efforts. These forces are the main cause of the relative and rapid wear of tooth, loosing the profile of tooth. It also combined with the additional aggressive environment thus bad lubrication, contamination and abrasion phenomenon. etc, cause important abrasive effect on the wheel. The spur gears are made of steel of high carbon content (of a 0.40 to 0.45 %).

The manufactures use to produce this kind of wheel with hardness from 160 to 200 BHN (Brinnel Hardness Number).

Due to the high cost of production of the spur gears. the users have forced to employ the welding techniques in order to (recover) the initial profile of teeth, and it provide a good way to extended the industrial life of the wheel and at the same time decrease the cost of maintenance. The technique of superficial filler for recovery of spur gears has wide range of application and it helps to achieve favorable economic results also. By using professional software package (COSMOS) a mathematical model of the wheel is developed from the point of view of thermal behavior. It is serving as base to carry out the optimization of recovery process sequence. The objective of this paper is to develop an automatic control system to recover a favorable profile of tooth keeping the physical and mechanical properties of the wheel in the entire surface of the body intact. The system is totally automatic and it's formed by various subsystems controlled by computer programs.

The final result obtained is an important starting point for performing the schedule analysis (dynamic and static) in the real time system implementation.

2 Automatic Welding System

The industrial robots in modern industries become in an important part of the automatic manufacturing systems. The future leads toward an automatic integration system.

The robotics applications in welding constitute a world tendency since few years before. They are essential part of robotic systems and flexible manufacturing process. This system has considerable advantages to maximize the quality and life of the cord and welded unions. In contrast to the traditional methods of welding, the automatic welding assures the warranty of satisfying the specifications of the design [15].

Many welding designers exhibit packages of flexible welding cells for a group of programmed robots. These packages facilitate the automatic generation of robot's trajectory to achieve a better position of robot arm to carry out the weld. The main advantages that offer the welding robotics systems are:

- Reduction of the work cycles.

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- Increase the flexibility and performance.
- Ease of installation and maintenance.
- High speed in the welding sequences.
- Improvemenilquality.
- Higher production.

2.1 Robotic welding process

2.1.1 Machine vision system

To produce a new identical profile from the decayed profile of tooth it is necessary to know the degree of wear that exist in each tooth; for that reason two-dimensional images of the teeth were taken, and then compared with the suitable pattern profile.

Image of the teeth are taken by artificial vision techniques using the MATROX© and compare it with ideal one and the result differences appear in shadows as shows in figure 1.

The acquisition of images is carried out by white and black camera (640 x 480 pixels) to get the resolution of the image smaller than 0.3 mm/pixel. This value of resolution is considered good according our application requisites.

With the information obtained from the analysis and images processing, it is possible to determine:

- Magnitude of the wear of each tooth.
- Angle between teeth.
- Numbers of welding runs required to perform by the robot.
- Area of the transversal section of the welding cord.
- Welding Sequence.

Taking periodically additional frames of teeth new welding sequences can dynamically be computerized.

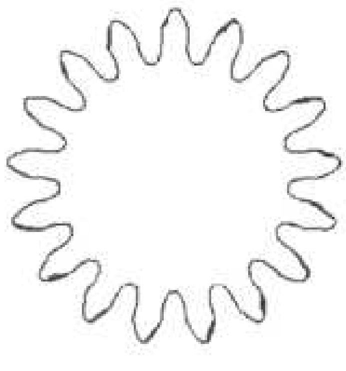

Figure 1: Profile of spur gear showing the wear of teeth.

2.1.2 Hardware Architecture

The general architecture of our system is shown in figure 1. It's composed of two computers, a robot with five degrees of freedom, an automatic welding machine, a rotation device controlled by motorized position control system and an artificial vision subsystem, i.e. camera with its optics and frame grabber, direct connected to one of the computers.

The operation of the system in figure 2 concerned with the following sequence of reaT time tasks:

1. Acquisition of images.
2. Digital processing of images.
3. Computing the static task sequence.
4. Computing the dynamic task sequence.

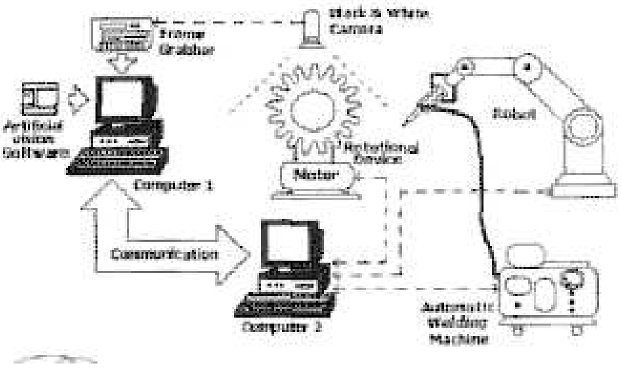

Figure 2: General hardware architecture of the system

We used two intelligent units (2 computers that can communicate between them) with specific functions to perform for each one. The computer number I is involved in the acquisition and pre-processing of the images; for that purpose a frame-grabber is inserted in the PC with a black and white camera coupled to this computer. The computer number 2 has the responsibility of governing three feedback control loops, i.e. the robot control, control of welding process and position control of rotational device. This second subsystem also assists the task of supervision and the visualization (display) of system parameters. The whole system is characterized by two operation modes: one is image acquisition and the second one is sequencing of work and scheduling task. Both modes are composed of tasks that must be executing in real time. See section 6.

3 Thermal processes in the welding

The heat transfer of the welding arc, produce higher values of temperatures in the neighborhood of the cord during the welding. Due to the rigidity of the component elements of a welded structure, undesirable deformations and strong tensions may be appearing in the metal structure. This phenomenon produces modifications in the dimension and shape of the body and in their mechanical and physical properties. In those cases where the deviations of dimensions of the welded construction are greater than the permissible values established by standards, it is necessary to take special considerations and care in order to avoid that -these problems do not arise during the welding routines.

The study of the thermal processes that take place during the welding is a fundamental topic that concerns to the welding theory. Most of physical phenomena observed during the welding will be possible to explain if an adequate thermal analysis of the metal body is considered. The study of thermal welding process is related to the distribution of heat during the heating of the metal by different sources. The influence of them on the metal properties and in the thermal cycle of -metal is the basis of causing structural transformations. The distribution of temperature along the surface or volume of a metallic body is called Fields of Temperature. It represents the temperature distribution at all grouping points of the body at any time. These fields of temperature can be represented graphically or by mathematical expressions.

If the source of heat is mobile the distribution of temperatures is not uniform in the depth of the body. the isotherms become more complex curves and then can be represented approximately by elliptic curves. Figures 3 (a) and (b) show the fields of temperature (isotherms) caused by the heating of a foil of steel with an immobile and mobile source of power (Q=750cal/sec) respectively.

In our particular case the process of heat transfer can be considered involving three stages, that is:

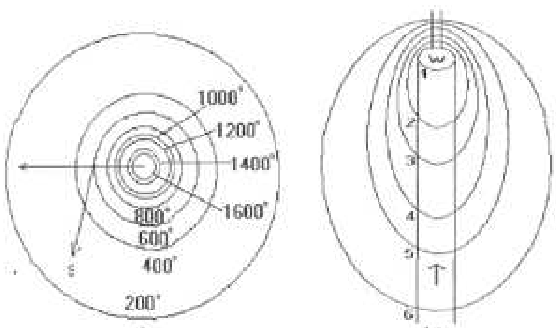

Figure 3: Isotherms caused by (a) immobile source and (b) mobile ŝource.

Thermo-saturation stage: in this stage the temperature around the source of heat is increasing. Quasi-stationary stage: the distribution of temperature is stationary referred to a system of mobile coordinates that are moving together with the source of heat. Leveling stage: the temperature tends to be equal in the whole body after the welding arc has extinguished.

4 Mathematical modeling

The modeling of the welding process under different circumstances, allows obtaining metal structures that guarantees a higher operation levels with lower possibility of failures and stresses in the materials. An appropriate process of mathematical modeling of the system allows evaluating the thermal conditions of any body during the welding process. The deformations and tensions that may appear can be evaluated with precision and reliability taking appropriate decisions regarding control strategies to improve the welding quality.

4.1 Semi infinite solid approximation

Simplified calculation and mathematical assumptions must be taken in consideration to make a good simulation of the welding system. They involve heat process and sources of heat between others.

In fact, the analysis of the processes of transfer of heat is necessary and useful to perform any simplification in the mathematical formulations. The distribution of heat in a body depends fundamentally on the forms and dimensions of the body. The thermal field is abruptly modified by the vicinity of the borders (or limits) of the body respect to the source of heat. For this reason different simplified scheme of the body is taken in consideration to perform the computation.

Previous studies were made with the assumption of the semi-infinite solid [11]. The approximation of a rigid body by a semi-infinite solid body is based under the consideration that the body has sufficiently large dimensions in comparison with the source of heat. It allows to consider that the distribution of the heat in the remaining surfaces and limits of the body are not affected by the source of heat; because they are sufficiently ('faraway ¿from the source of heat and its presence do not modify the heat distribution through the body.

Past theoretical studies about the physical phenomena related to welding were developed by numerous authors with the objective of determining the dependence of the distribution of the temperature inside solid bodies during the welding, [7], Their solutions were based on ideal approach of infinite solid or semi-infinite body. Solutions based on such ideal assumptions (semi-infinite solid body) were studied to determine the temperature distribution with time inside solid bodies during transient heat process [6][8].

Ideally, when a solid body tends to infinite in one dimension, is possible to characterize it for a simple identifiable surface and considered the body as a semi-infinite solid. If a thermal change occurs suddenly in the body surface, one-dimensional conduction of temperature will take place inside the solid.

The semi-infinite solid assumption provides a profitable idealization for many practical problems. In our particular case it is used to analyze the effects of heat transfer in the wheel, when it is subjected to the action of the welding cord in the filler process.

The equation that represents the transient conduction of heat in a solid semi-infinite is:

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \tag{1}$$

The initial condition of body temperature is T(x,0)=T_i and the internal limit condition is T(∞,t)=T_i

$$Where: \quad \alpha = k(\rho c)^{-1} \tag{2}$$

x: body depth (m)

α: thermal diffusivity (m^2/sec)

c: specific heat (J/Kg ^{o}K)

k: thermal conductivity (W/m ^{o}K)

ρ: body density (Kg/m^3)

T: temperature (^{o}K)

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We considered that the welding process is developed under the condition of constant flow of heat applied to body surface of wheel, see figure 4. Parameters α, c, k and ρ represent the thermal properties of the body.

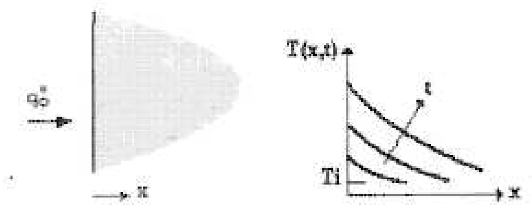

Figure 4: Temperature distribution in solid semi-infinite body subjected to constant flow of heat.

In previous analysis the temperature distribution as a function of time and depth in semi-infinite solid body approximation is:

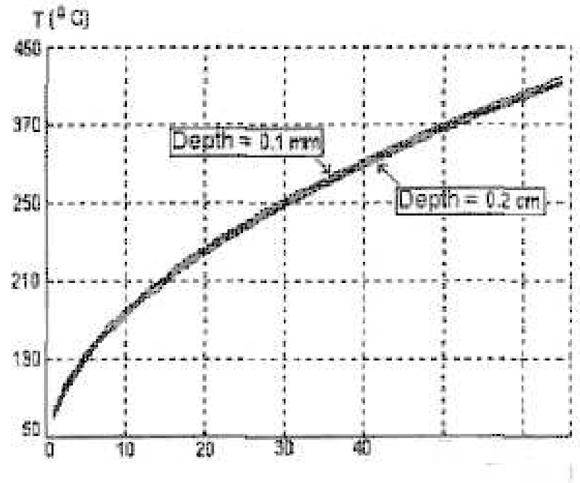

Figure 5: Results of gradient of temperature in the spur gear during heating stage by applying semi-infinite solid approximation

$$T(x,t) - T_i = \frac{2q_o(\alpha t/\Pi)^{1/2}}{k} exp\left(\frac{-x^2}{4\alpha t}\right) - \frac{q_o x}{k} erfc\left(\frac{x}{2\sqrt{\alpha t}}\right) \tag{3}$$

T(x,t): temperature gradient (^{o}K)

T_i: initial temperature of the body (^{o}K)

q_o: flow of heat applied to the surface of the body (W/m^2)

erfc: Gaussian complementary error funciton

4.2 Finite-difference formulation

Simulations carried out with semi-infinite model demonstrated that it is possible to use it for the thermal analysis of the wheel; nevertheless certain quality requirements necessary for the automatic system were not satisfied by it. Because of this we decided to employ the finite elements analysis which is more accurate in mathematical model, although it consumes more machine computation. For that purpose we used the Laplace equations that describes the conservation of heat in order to develop a heat balance from finite differential elements analysis [11], [12].

5 Simulation

During the entire welding recovery process the wheel receives a constant flow of heat (i.e. heating energy contributed by the welding cord). This heat transfer is present during the whole recovery process. For that reason mechanical characteristics and properties of the body must be periodically checked to assure the quality of recovery process.

In order to evaluate the thermal behavior of the body under these conditions, its necessary to know the temperature gradient variation in a body. This information constitutes a starting point to establish an appropriate automatic welding sequence and consequent control strategy to follow.

From the thermal point of view the mathematical model described in section 4.1 give us a representation about the heat transfer and dissipation of heat during the automatic recovery process under real conditions [6] [7].

In welding process, because of heating and subsequent cooling process, mechanical deformities and internal forces appeared in the vicinity areas of the welding cord. Considering the general characteristics of the system, we decided to use the finite element analysis (finite mesh model) to evaluate the thermal behavior and transient temperature phenomenon involved during the welding. Previous studies have demonstrated the accuracy and validity of this model rather than semi-infinite solid approximation. [11], [12] The model of finite mesh consists of dividing the whole solid body in several small elements (finite elements). The finite element model is very useful to perform the gradient analysis because a fine mesh structure is possible to develop in order to achieve a good resolution and accuracy necessary to evaluate the temperature gradient in each individual point (node) near of the welding cord. With this purpose a fine mesh was carried out in the proximity of the cord, whereas a thick mesh is preferred to use in points located faraway of the cord (see figure 6). It's a warranty of computational cost reduction without necessity to sacrifice accuracy and resolution. Others researchers [10] demonstrated the validity of this strategy applied in the finite element analysis.

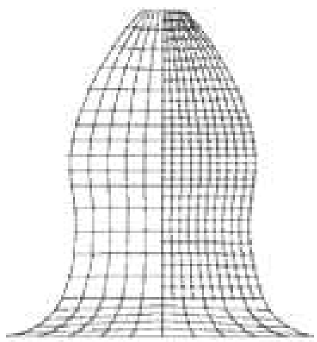

Figure 6: Front view of the tooth where fine and thick mesh are appreciated.

We employed the COSMOS package software to develop the simulation. It is professional software that has powerful capabilities to perform Unite element structures in variety of bodies and also provides appropriate commands to control the density and shape of the mesh.

In our particular case, adequate two-dimensional profile of the wheel tooth was drawn in AutoCAD and then it was imported to the COSMOS where finally the corresponding pattern was designed in three spacial dimensions. The adequate density of mesh was arranged - fine mesh in the areas of application of heat and gross mesh in faraway areas of the welding cord, fig 6.

The computational results of temperature vs time produce bi-dimensional arrays of data at each node. An illustration of temperature gradient at three random nodes is shown in figure 7.

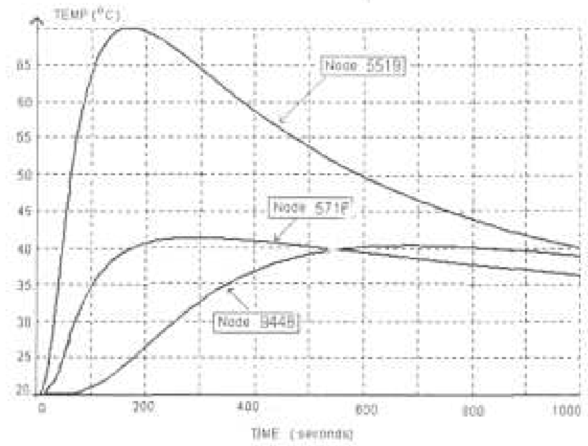

Figure 7: Temperature behavior of nodes 5519,5716 and 9446

6 Real Time System Implementation

Practical implementation of the automatic system in real time was done with the results obtained by the thermal simulation; it was also considered that the system under study is classified as a Soft Real Time System because temporal specifications of the tasks are not critical.

The scheduling analysis of real time tasks was performed using the Rate Monotonic Analysis method (RMA) [5],[14]. The tasks were defined according to their temporary specifications: period, deadline, time-delay and execution time. The time characterization of tasks and the scheduling policy were established according to the architecture of figure 5*. Two modes of operation were defined - Mode 1: Image Acquisition and Mode 2: Control Sequence; where the task priorities were set inversely proportional to the period of the tasks [11]. See table 1.

The variables Pi and Ci represent the period and worse case execution time respectively of the tasks in each operation mode.

An appropriate behavior of real time system is obtained. Time chronograms of scheduling tasks using RMA method are shown in figures 8 and 9. All the tasks are executed on time, i.e within their period of time.

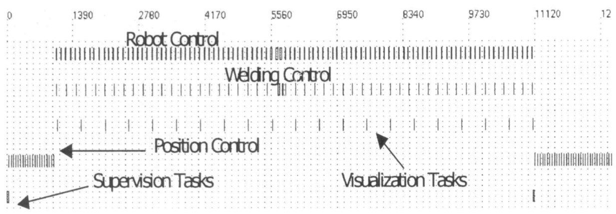

Figure 8: Chrongram showing the execution time of the tasks in the Mode 1

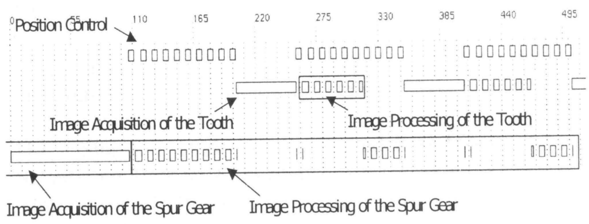

Figure 9: Chrongram showing the execution time of the tasks in the Mode 2

The computer number 2 (figure 2) has installed a real time operating system RT-Linux and the control algorithms of all subsystems were implemented using C++ programs.

7 Conclusion

The study and analysis of the affectation that can suffer the spur gear during the process of automatic welding is very useful and indispensable to implement the automated control of the system.

The simulation offers useful results and experimental data, among them we can mention: Temperature versus Time curve for each node, temperature gradient in the body, cooling speed, temperature distribution, etc. This valuable information permits to perform an adequate analysis and selection of the best sequence of welding. In addition, the accurate distribution of temperature in the wheel facilitates the realization of automatic welding process with better quality and efficiency.

It demonstrates the validity of the thermal model to the study the gradient of temperature in the wheel and to use that information to establish the right sequence of operation for the system.

The proposed architecture improves the quality and efficiency of the welding process. It's suitable for industrial environments, and it is also very flexible and technologically adaptable for another type of machine elements with different weight and complexity. This automatic system has large utility for similar industrial applications.

All the tasks are executed within their period of time according to the scheduling policy to assign the priorities. Tests performed under real condition demonstrated that the automatic system fulfill the performance specifications. It is also stable and controllable.

Tasks involved in the Operation Mode No. 1	
Image Acquisition of the spur gear and digital processing	P_1 = 45 sec C_1 = 210ms
Image Acquisition of the tooth and digital processing	Asynchronous C_2 C_2 = 210ms
Tasks involved in the Operation Mode No. 2	
Robot Control	P_1= 18 ms, C_1 =4 ms
Welding Control	P_2= 80 ms, C_2 =0.80 ms
Position Control	P_3= 100 ms, C_3 =12 ms
System Supervision	P_4= 1 sec, C_4 =0.25 ms
Visualization	P_5= 1.5 sec, C_5 =0.35 ms

Table 1: Temporal Specifications of Tasks

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