The results of investigation of highly curved car body surfaces by optical methods

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The improvement of highly curved car panel surface inspection is presented. New idea of inspection apparatus with real time vision system, specification and analysis of the basis, definition of a panel curvature are described. Interim inspection test stand has been established and preliminary results obtained and presented.

1. Introduction

In modern automotive industry quality is one of the most important factors of all. High requirements force manufacturers to apply technological advancements in an area of modern design as well as control techniques. Nowadays all the automotive companies employ various methods of quality control, especially sophisticated for expensive brands as Mercedes, Volvo, Lexus, Jaguar, Alfa Romeo etc.

There are two general methods of surface inspection. The first one is a conventional measurement technique allowing the detection of most of the dangerous or interesting flaws. Generally they depend on direct contact with inspected surfaces. This issue generates a few problems. The capabilities of inspecting metallic and non-metallic parts are different so one system does not provide all expected data, some surfaces are not available for contact-detectors. Besides, the methods are too slow and imprecise. Additionally in modern automotive industry over 90% of die stamping panels are curved surfaces what in many situation eliminates use of conventional inspection methods and systems.

In response to modern requirements optical methods are an interesting alternative to conventional measurement techniques. More information and review is available for instance in [6]. Those methods provide full-field information without direct contact with a specimen, without marking or special preparations. These factors increase interest in modern heavy-duty optical systems.
This paper shows the way of optical system improvement in surface inspection. It is based on the US Patent 5086232.04 which was invented, designed and applied for Jaguar Cars Limited [9, 10]. The present system which detects local surface flaws on a car body panels of Jaguar X100 Sports Car has been in use at OGIHARA Europe Limited press shop in England for the recent 3 years. This paper extends the idea mentioned about in previous publication [15] and shows the results of investigation of highly curved surfaces.

2. Present system [9, 10]

2.1. Description

As written in the patent [9] the present system invented by S. Maguire, K. Sivayoganathan and V. Balendran, is provided to detect material flaws and mistakes in the shape of car panels. The apparatus is shown in figure 1.

![Present system apparatus in Research Department of The Nottingham Trent University.](image)

The general idea of laser inspection developed in Department of Mechanical and Manufacturing Engineering at The Nottingham Trent University (TNTU) is to allow quality “post-process” check of car panels especially “A-zones” panels which are highly visible areas of a car.

Present automotive manufactures and their customers expect 100% defect-free “skin” panels in the range of human eye capability of detecting errors as small as $0.8 \times 10^{-5}$ mm [3].
Of course, the present system is suitable for inspecting the most common material flaws like: dents, dings, ripples, swamps, wrinkles, creases and abnormal shape of panels. The smallest defects of size under 20 microns are not important because such small flaws are covered during the painting process.

2.2. Specification and analysis

The source of coherent visible light is a low energy Helium Neon laser attached to fixed position on the apparatus’ frame. Thanks to special set of optical lenses, fan shaped beam of an angle about 20° is achieved [10]. This solution enables testing surfaces on the width of approximately 25 cm.

![Schematic diagram of the present system](image)

The process of detection (see Fig. 2.) starts from the source of the laser beam (A) whose output is directed at the surface of a panel (B). A fan shaped planar beam (a) reaches the surface with high angle of incidence (about 80°) where it is reflected with low angle (about 10°) in the direction of the detecting screen (C). In the present system the shape of light is scattered by the use of special optical device attached to the output of the laser.

Thanks to the use of shaped beam light, the images of both curves are created both on the screen (C) and a surface of a car panel (B). The amplified screen image (d) of the surface is useful for detecting the fails of material but the curve on the real panel (b) is used for fixing the position of a fault.
Analogue cameras record both images to further analysis. The record of screen image made by parallel camera (E) is an amplified trace of temporary laser’s beam position and is used for checking the quality of surfaces. Scans took by the camera perpendicular to the surface (F) are used for indexing the position of flaws and for creating a map of flaws. These scans are independent but together they are very useful for detecting and fixing flaws.

The set of all curve images from a separate channel creates a scan of surface separately for real curves from a panel and reflected and amplified from a screen. The examples of scans are shown in figure 3.

![Deflected image scan](image1)
![Real image scan](image2)

**Fig. 3. Sets of real and reflected scans for single pass.**
Rys. 3. Zestaw zdjęć krzywych rzeczywistych i odbitych dla pojedynczego przejścia

### 2.3. Elements of the apparatus

The main idea of the described above present system is to generate an electronic (digital) signal proportional to the light incident onto a sensitive screen. An output signal is changed into an electric (analogue) signal easy to further analysis. This transformation is the main, well-known difference between CCD and digital cameras.

In this way the camera can be treated as the primary data-input device and strictly co-operates with fast analogue to digital converters to enable computers to “grab” single video frames. Figure 4 schematically represents a computer vision system employed in the apparatus.

CCD cameras for metric work have normally an array of about 500×600 photosensitive elements so that the picture is almost compatible with a nominal grabbed image 512×512 frame size. Moreover, the camera produces an analogue output signal that is suitable for the monitor and gives “live” picture of the inspection.
3. Development of the system

The aim of the paper is not to create strict definition of curved surfaces or define them into one of four surface groups: flat, rotational, ruled or curvilinear. Thus expressions as quasi-flat or curved surface should not be meant as a mathematical definition of objects. In this paper, except already implemented system for quasi-flat surfaces, an idea and preliminary test results of the improved system for highly curved surface inspection are proposed.

3.1. The idea

Firstly, an experiment was proposed that could solve the problem of curvature of body panels. In the present system the object of inspection are a car door panel shown below in figure 5.

In the present system the general idea is to divide the range of inspection into belts of width about 20–30 cm (Fig. 6). It is obtained by the use of 2×5 CCD cameras and enables the test car body panel as shown below.
The object that was determined as a task object for the development is the wing body panel presented in figure 7.

Following the idea, highly curved surface (in this example curvilinear surface) can be divided into belts of various widths along \( x \)-axis, what is presented in figure 8 and one-step scheme on figure 9. In the analysis, to distinguish different types of surfaces is not priority due to the class of inspection output. The development and the system itself should supply qualitative information instead of quantitative values. Thus it is not obligatory to keep the line where incidence angle is equal to reflection angle.
The problem is to enable the moves in 3 directions:
- along y-axis, to enable a move across a panel,
- along z-axis, to keep the distance between the device and the surface,
- rotation round x-axis, to enable parallel position of device against inspecting panel.

This experience generates an issue of the definition of "highly curved" surfaces. It is not strict because it can also be comprehended as a high angle of curvature along one axis (examples at the top of this page) or as a curvature along two, x and y-axes and a highly curved small area of the object of interest.

3.2. Improved system

Basis of improvement was to define the idea of whole inspection system for highly curved surfaces. One of the solutions is to design a device — a small, hand manipulated, mouse-shaped apparatus for detecting flaws in wide areas of panels for example boot or bonnet panels. We expect a high ratio of curvature but appearing along x-axis (or both x and y-axes). Moreover, the inspection is applied only to specially interesting parts of a panel particularly exposed to defects. If so it creates a few problems:
- the process of searching would be manual so it can be inefficient and very subjective,
- the present system can be easily adapted to detect flaws on flat or nearly flat kinds of surfaces,
- the best solution should join the possibility of inspection of highly curved surfaces as well as flat ones.

To enable the detection of flaws on a highly curved surface it is necessary to:
- irradiate light directly to the specimen’s surface; it’s possible to use wider than visible spectrum of waves but the project claims the development of the present system,
- expand up a beam to a belt/fan shape to enable detecting a bigger visual field by the use of a cylindrical lens or other optical devices,
- detect scattered and reflected light,
- make allowance for incident angle of a part of specimen, changing the position of detection changes the angle of normal to the surface,
- shorten the way of rays by using dispersal lens,
- detect any irregularity of curve by:
  - amplyfing the real curve onto a detection screen, where the image curve can be saved,
  - use high-sensitive CCD cameras to get a good quality output signal.
3.3. Design of apparatus

The most important problem in case of curved surface inspection is defining the proper method to obtain a reflected image on a focusing screen. After reflection from highly curved surface a laser beam, earlier flat and fan shaped, changes into three-dimensional dissipated (scattered) and hard to define shape. It is impossible to deflect a beam directly onto the screen because the screen would have to be located below an inspecting surface or any unforeseen location so this solution is unacceptable. The situation changes if a concave mirror, which would keep a reflected laser beam within the area of detecting screen, is added between the surface and the screen. Brief diagram of the apparatus is shown in figure 10.

The main idea of the apparatus is to enable flaw detection by hand-operated item with a real-time video control system. Two points (dark spheres) are a base of the apparatus where third one (below the body of laser) can adjust horizontal position due to change of surface curvature. Adjusted and fixed spherical mirror focus deflects rays onto focusing screen. Thanks to mobile laser level depending of curvature, main fan axis always reaches same place on the surface and can be easily re-deflected onto screen, where is picked up by CCD camera. Flaws are detected with 2–2.5 curve amplification by a computer system equipped with frame grabbing hardware and software.

Fig. 10. Idea of the apparatus for highly curved surfaces.
Rys. 10. Idea aparatury dla powierzchni mocno zakrzywionych
4. Test results

4.1. The stand

Computer analysis defines a spherical concave mirror as a third purposeful element between inspected surface and a focusing mirror. It was necessary to run an experiment, which could prove correctness of the preceding results. As an assumption to the tests were computer analysis, thus main dimensions between elements what enables to set the apparatus (Fig. 11. and 12.).

Before the run, computer model was made and tested if can answer and prove expected data. The experiment was carried out in Experimental Physics Department at Wroclaw University.
The apparatus consists of:
- strong source of visible radiation (a lamp) coming through a fissure (instead of a laser),
- spherical concave mirror $R108 \ D = 136$,
- white foggy focusing screen,
- sensitive photo camera with a tripod,
- set of stands.

4.2. Specimens

Two different specimens were the objects of the test (Fig. 13). First one is a flat belt of metal with small dent (a defect) as a result of press mistake. Second sample is metallic cylinder $\varnothing D = 96.8 \ [\text{mm}]$ with visible inspection width $l = 15 \ [\text{mm}]$.

![Flat and cylindrical samples](image)

Fig. 13. Flat and cylindrical samples.
Rys. 13. Próbka płaska i cylindryczna

4.3. Results

All information shown below consists of test results. Their main purpose is to answer whether a concave mirror can enable detection of flaws and a shape of curvature of inspected surface.

Test was carried out with flat specimen. In the picture (Fig. 14) there are two visible curves. Small U-shaped one is the real image of the curve on the inspected surface. Thick curve is the image on the focusing screen. Test detected that “flat” surface in matter of fact is a curved surface.

In the picture (Fig. 15) there is shown image of the amplified curve from the focusing screen. The curve is a straight line what means that this particular place on the surface of detection is flat and free from defects.
The line in the picture is highly curved what represents a flaw on a real surface. There is a visible difference between the picture with detected flaw (Fig. 16) and the picture representing “only” curvature of the surface (Fig. 15). Moreover relation between Fig. 15 and 16 is similar to referring place Fig. 3 where a flaw was detected.

Test carried out with cylindrical specimen. In the picture (Fig. 17) there are two visible curves. Thin one is a real image of the curve on the inspected surface. Thick curve is the image on the focusing screen.

In the picture (Fig. 18) there is shown an amplified curve representing appropriate part of a real surface. No flaws detected.
5. Conclusions

This paper presents general idea one of well-known optical inspection system invented and developed in The Nottingham Trent University. On this basis highly curved surface definition has been carried out what enabled to specify requirements for improvement. The development of particular optical apparatus for curved objects was presented. The test stand scheme and pictures, test results were included. Either CAD analysis of ray traces and test results from laboratory proved that additional element a spherical concave mirror in triangle of apparatus laser — surface — camera enables detection of a shape and surface flaws on highly curved surfaces. It seems that the idea of a small, hand-operated apparatus with mobile level of laser beam associated with concave mirror can improve modern methods of investigation in quality engineering. The improved system can be easily applied into quality systems of modern manufacture in many different parts and steps of process as press forming, molding and painting. The goal of the improvement would be an application of the apparatus into quality systems of modern manufacturing especially A-class products of automotive industry.

Presented work can be treated as a next step for further improvement in test quality area of engineering for motor car industry. Further work assumes research in an issue of real-time inspection what is necessary for the particular solution. Moreover the idea of additional element a mirror in the system is not closed only within hand-operated apparatus and can be changed appropriately to expectations. The system is designed to detect local surface flaws on car body panels what means qualitative evaluation of panel quality but it can be further developed to enable inspection of curve shape including quantitative description of objects. The next step of improvement can be for instance a method of flaw measurement or curvature radius of a surface.

Moreover the system may be used for wider purpose to enable quality inspection for other branches of modern industry.
References


Wyniki badań metodą optyczną mocno zakrzywionych powierzchni nadwozi samochodowych

Streszczenie

W pracy przedstawiono rozwinięcie zagadnienia badań optycznych powierzchni nadwozi samochodowych mocno zakrzywionych. W zawiązaniu do US Patent 5086232 opisano nową ideę aparatury kontrolnej z systemem optycznym pracującym w czasie rzeczywistym, a także zawarto charakterystykę, analizę teoretyczną oraz definicję krzywizny powierzchni. Przedstawiono wyniki uzyskane na stanowisku badawczym.