# Detection of defects in the manufacturing of electric motor stators using vision systems: Electrical connectors

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***Abstract*— There are many applications which make use of electric motors. These machines are mainly composed of a rotor, which is the rotating part, and a stator, the fixed part which creates the magnet field that rotates the rotor. Regarding induction motors, the stator manufacturing process is much more complex than the rotor one, so its rate of defects is also higher. In order to control these events, inspections are commonly done by human operators, which are subjected to fatigue and lack of attention. This paper presents the development of an automatic vision system to inspect defects of electric motor parts in assembly lines, specifically the force-induced disconnection of the stator power cables inside the electrical connector. A test rig and software routines for implementing the proposed inspection principles have been developed. A case study using 20 connectors of real motors was proposed for evaluating the vision system and the results showed that it was able to correctly identify 100% of the defects.**

## I. INTRODUCTION

The electric motor possible applications are countless in many different fields of the economy. The three-phase squirrel-cage induction motor is the one which is widespread in the industrial sector. However, the one-phase model the most used in both residential and commercial applications. This equipment has two main parts: the rotor and the stator [1, 2, 3, 4]. Figure 1 shows a typical single-phase induction motor and its relevant parts for this study: (1) rotor, (2) stator, and (3) electrical connector.

Stators are more complex to manufacture than rotors, thus they are subjected to many tests along the production line and also when the assembly is finished. Through the monitoring of a stator production line, the main sources of defects have been enumerated. In this observation, it was concluded that the disconnection of a stator power cable, which hereby will be denoted by short as DSC, is relevant and its detection is difficult to be made visually by human operators.

In quality control, it is noticeable the increasing use of automatic inspections, in which vision systems (VS) occupy a major space considering its reliability in contactless

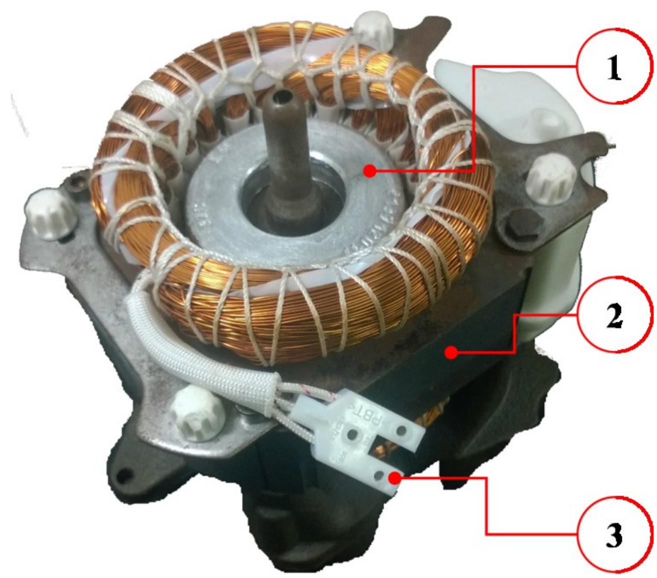



Figure 1. Parts of an electric motor.

inspections [5, 6, 7]. Even though automatic inspection methods present many advantages, visual inspections in industry are yet commonly done by human operators, which are subject to lack of attention, fatigue and subjectivity, and are costlier. This makes the use of VS even more interesting [8]. This fact makes DSC a strong candidate for automatic inspection.

The existing literature presents good results of VS in industrial direct and indirect processes. The work of [9] has shown the importance of VS for industry. In [10] segmentation and border detection techniques have been used to oversee the phase interface of oil sands inside decanters, controlling thus the admission of sand in the system. In [11] researchers used an industrial camera to replace a colorimeter in order to find the color of meats, thus inferring about their quality. In [12] a VS has been developed to measure the form of potatoes, also determining their quality. A portable measurement system using photogrammetry has been projected to inspect the outside of ducts of oil industry in [13]. Regarding stators, work [14] consists of an experimental analysis of the required conditions to replace the human inspection of stators by VS. Finally, in [15] the work of the companies Pontiac Coil and Vision Traceability Group in terms of inspecting stators using machine vision techniques is described. It is noticeable that the detection of defects in industry using VS has wide applicability [9].

Thus, this paper proposes the use of VS to inspect DSC. A prototype of test rig based on mechanical traction and vision inspection has been developed and a case study considering connectors used by a manufacturer of electric motors has been performed. Results have been gathered and discussed, considering a goal of 99.7 percent of correct indications.

In section II, the proposed solution is detailed, including the defect description in section A, an overview of the proposed test rig in section B, and a description of the proposed algorithms in section C. In section III, a case study is presented and its results are shown. Finally, section IV summarizes the main ideas and conclusions of this paper.

## II. PROBLEM DESCRIPTION AND PROPOSED SOLUTION

This section begins with DSC defect description, in subsection 2.1. Then, in section 2.2 the proposed test rig is characterized. After that, the proposed algorithms for image processing are explained in section 2.3.

### *A. Defect description*

The electric motor stators studied in this work have three terminals of the “clip” type and, when attached to a plastic box, are called electrical connector (Fig. 2). The detail on this figure shows how usually the DSC visually appears: a misplaced electric clip appears in the connector opening, while the correctly placed ones do not.

The disconnected power cable defect is characterized by an improper union of the metallic clip and the plastic housing of the electrical connector. When it happens, relative movements between clips and the electrical connector can occur, allowing the electric contact to be temporarily suspended. Because of these movements, the electric tests made in these motors in the end of their assembly lines can

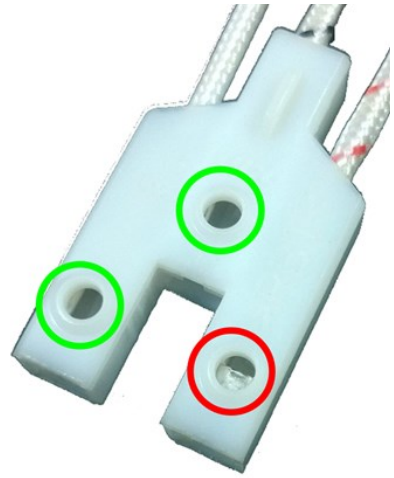


Figure 2. Electrical connector: correctly placed clips are circled in green and a misplaced one is circled in red.

fail to detect the defective samples since these moves can happen after the quality evaluation. Hence an investigation of DSC is needed.

### *B. Test rig*

According to the manufacturer, each electric clip resists being strained by an equivalent for of 34 N without coming loose from the plastic housing. Thus, a test rig which can apply the admissible load over each clip has been developed (Fig. 3). The rig is composed by a pneumatic cylinder FESTO DPZ-10-25 P-A, a base structure made of AISI 1020 steel and springs. To capture the images, a Logitech Pro 9000 webcam has been used, in order to create a low-cost system.

Figure 3. The test rig .

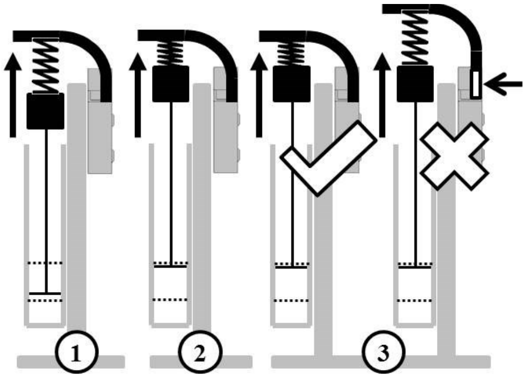



Figure 4. Schematics of how the test rig works.

Fig. 4 shows how the mechanism works. The compressed air enters the piston, forcing it to move up (stage 1). As the upper structure with the springs moves up, it pulls the cables that are connected to the clips (stage 2). A clip that is correctly attached to the plastic housing is able to hold the movement by compressing the spring. On the other hand, a clip with poor attachment will be released (stage 3). This allows the defect to be visually detectable using the camera. Therefore, the state of each spring on stage 3 can be used as confirming information about the quality of the attachment of the clips to the plastic housing.

*C. Algorithms*

An image captured by the camera using the proposed test rig is shown in Fig. 5.

Based on this image, the algorithm, which has been implemented using LabVIEW® and its Vision Development Module, follows the steps shown in Fig. 6.

The first step of the algorithm is locating the connector in the acquired image, so that it becomes possible to use its coordinate system to set all the position parameters of the tools which will be used in the sequel. This recognition is done based on a pattern detection function, which uses a database of images of connectors under different lighting conditions.

Once the connector position is known, the next step is to threshold the image aiming at the enhancement of the contrast

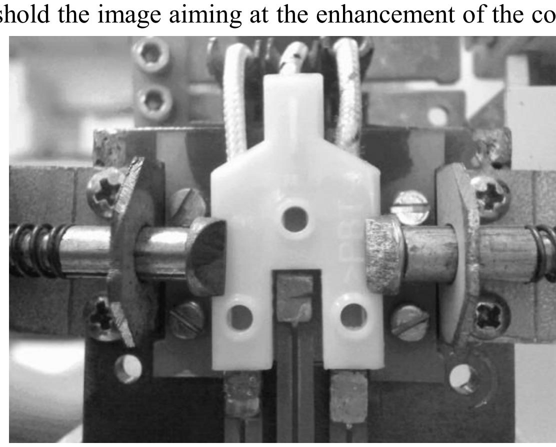


Figure 5. An image captured by the test rig .

of the region of the holes, one of the possible locations to inspect the clip position. The value which was used to establish the threshold was the default 127 (50% of the grayscale of an 8-bit image), since it has presented a good result on preliminary tests and the illumination conditions do not vary significantly from test to test. This step is illustrated in Fig. 7, where a case without any defect is shown in the upper part and a case with a defect in the upper clip is shown in the lower part of the figure. After using the threshold function, the difference between a hole with defective and proper clips is enhanced. This difference can be seen using both the shape and dimensions of the circles that represent the hole on the image.

Considering this, three different techniques have been developed to be used redundantly, in order to enhance the reliability of the tests.

The first one (a) uses a circumference detection function in the threshold image. This function uses the Danielsson's distance mapping in order to find the circumference. Since the holes have the same specific diameter, it is possible to assume that detected circles with diameters different from the expected one are the holes where DSC is present. The algorithm returns the number of circles which diameters are inside a predefined interval. Therefore, the indication of a number of circles different from three indicates the existence of a defect. The possible results of this technique can be seen in the Fig. 8 (a): in I, a defective connector; in II, one without any defect.

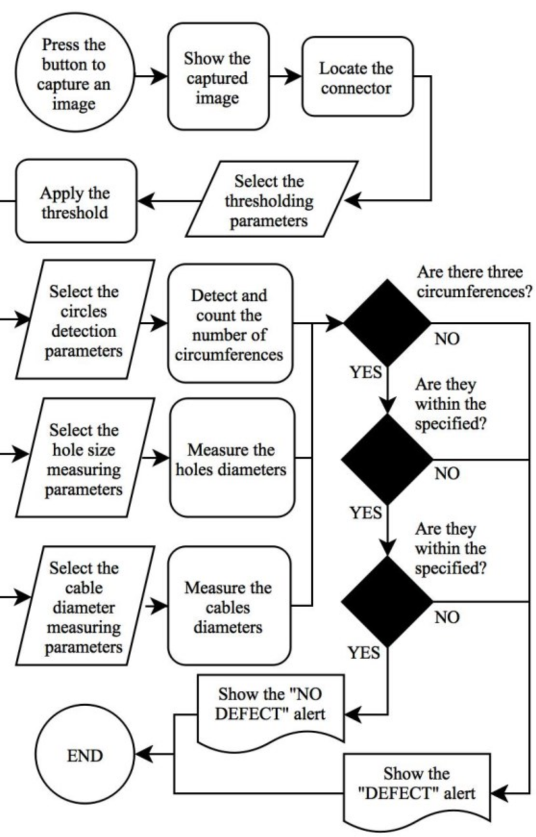
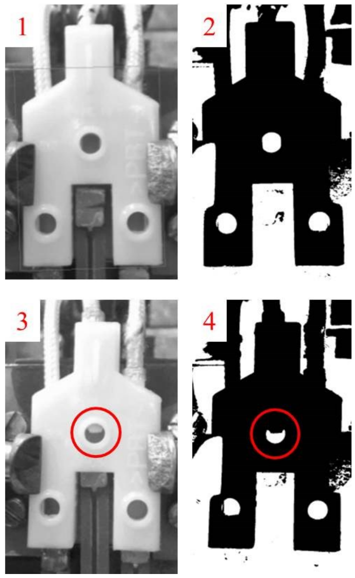



Figure 6. Flowchart of the algorithm.




| Legend | |
|---|---|
| 1 | Electrical connector without defect |
| 2 | Thresholding of (a) |
| 3 | Electrical connector with defect |
| 4 | Thresholding of (b) |

Figure 7. Comparison of images with and without the defect.

The second technique (b) uses edge detection and distance measurement to determine the size of the circles. The edge detection tool uses the gradient of gray level intensity to determine if there is an edge on the image. As it can be seen in Fig. 8(b), vertical blue lines are used as regions of interest (ROIs) to edge detection algorithms which determine points

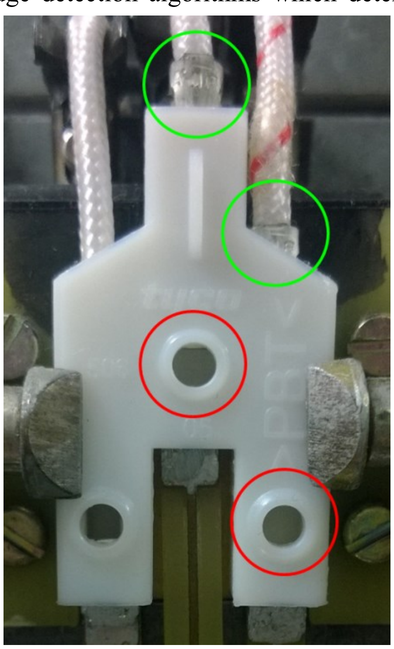


Figure 8. Two DSC in an electrical connector. The green circles show the clips appearing above the electric clip and the red ones show that the defect could not be detected by methods (a) and (b).

(red rhombuses) in the beginning and in the end of the hole. The distance between these points is measured and compared with the known hole diameter. If this distance is smaller than the hole diameter, the algorithm indicates a defect.

Finally, the third technique (c) is slightly different. While the first and second ones analyze the holes of the electrical connector, this one monitors its upper part, as can be seen in Fig. 8(c). When the cables are tensioned, sometimes they are almost pulled out from the electrical connector and the defect does not appear in its holes, because the clip is situated above the hole, as can be seen in Fig. 9. Thus, it is necessary to inspect the upper part to identify the defect, since in these cases the clip starts to appear in this region and the clip width is different from the cable width. Therefore, using the ROIs shown in Fig. 8(c) together with an edge detection tool, measuring the distance between the detected edges, and comparing the result with the expected width, it is possible to detect the defect.

After implementing and testing each technique, they have been integrated in a software tool for the automatic inspection of connectors. Section 3 describes these tests and presents its main results.

## III. CASE STUDY AND RESULTS

This initial validation study has been performed in a laboratory environment. Once validated, it has been planned to test the system in the production line.

Twenty one electrical connectors from the same model were available to test the proposed system. In nine of them defects which represent real DSC have been introduced.

In Table 1 it is possible to see which cables have DSC for each tested electrical connector. It is also shown which detection technique correctly detected the defect.

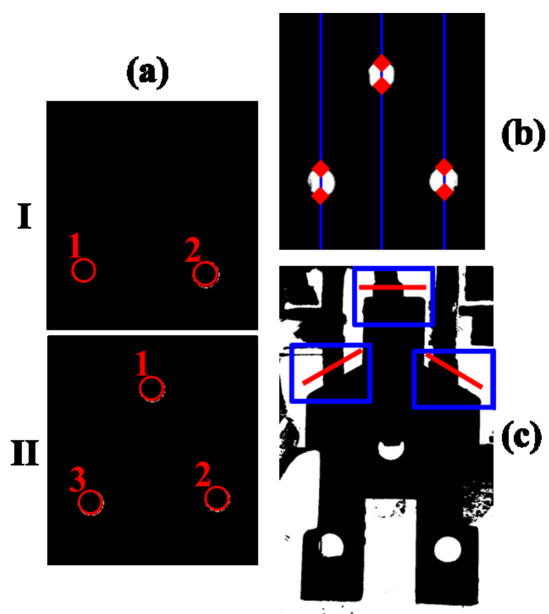



Figure 9. First, second and third techniques.

TABLE I. RESULTS OF THE DETECTIONS

| Electrical connector | Cable 01 with defect? | Cable 02 with defect? | Cable 03 with defect? | Technique (a): correct indication? | Technique (b): correct indication? | Technique (c): correct indication? |
|---|---|---|---|---|---|---|
| 01 | no | no | yes | no | no | yes |
| 02 | yes | yes | no | yes | yes | yes |
| 03 | no | yes | no | yes | yes | yes |
| 04 | no | no | no | yes | yes | yes |
| 05 | no | no | no | yes | yes | yes |
| 06 | no | no | no | yes | no | yes |
| 07 | no | no | no | yes | yes | yes |
| 08 | no | no | no | yes | yes | yes |
| 09 | no | no | no | yes | yes | yes |
| 10 | no | yes | yes | no | no | yes |
| 11 | yes | no | no | yes | yes | yes |
| 12 | yes | yes | no | yes | yes | yes |
| 13 | no | no | no | yes | yes | no |
| 14 | no | no | no | yes | yes | yes |
| 15 | no | no | no | yes | no | yes |
| 16 | no | yes | no | no | yes | yes |
| 17 | yes | no | no | yes | yes | yes |
| 18 | no | no | no | yes | yes | yes |
| 19 | no | no | no | yes | yes | yes |
| 20 | no | no | no | yes | yes | yes |

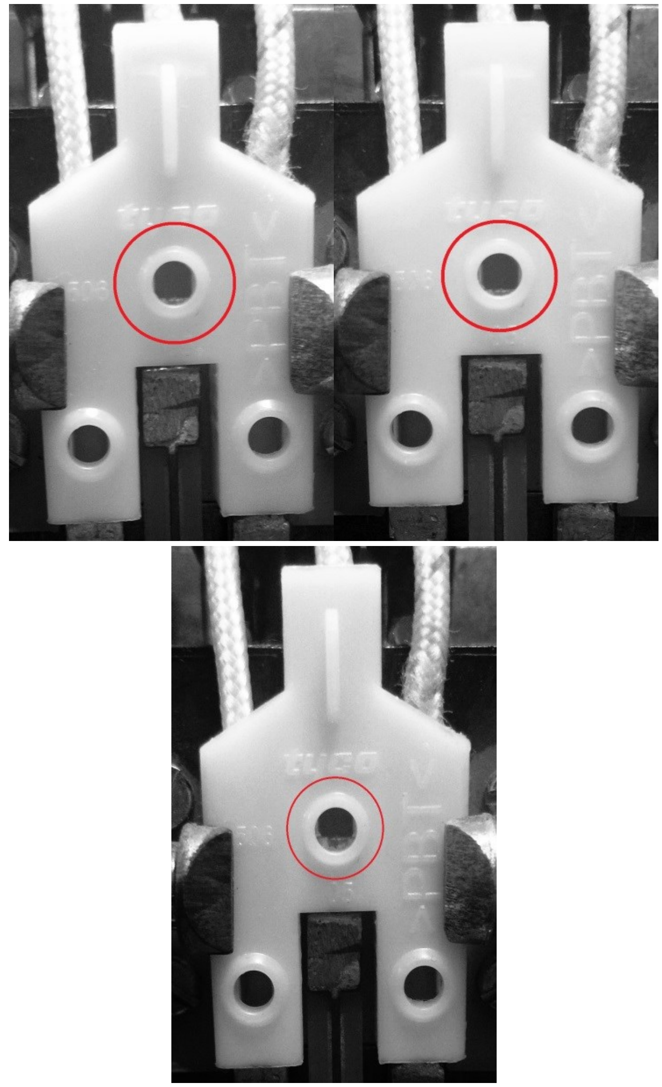
In Table 1, it is possible to see that the success rates of the techniques (a), (b) and (c) are 85.7%, 76.2% and 95.2% respectively. From the results of this lab test, it was concluded that the test rig functioned properly, correctly indicating all the electric connections with defect. Yet it is important to notice that the use of redundant techniques could enhance the reliability of inspection process, since in some cases two techniques failed but the third one allowed the algorithm to identify the defect. When the techniques were redundantly employed, all the analyzed defects were detected.

One example of the situation where two techniques fail and the third one is well succeeded can be illustrated by the electrical connector number 10, which actually is the sample shown in Fig. 9. In this figure, it is possible to see two cables (02 and 03) with DSC, but the defects could only be detected by method (c), as can be seen in Table I. This happened because the force applied to the cables pulled both clips to a position that is above the connector hole, thus both inspection methods based on analyzing the hole characteristics failed.

Some other cases reassure the importance of having three different algorithms working together in order to enhance the test reliability. Besides the previously discussed situation, which is illustrated in Fig. 9 and characterized by cases number 01 and 10, other cases presented conflicting indications among the proposed methods: cases 06, 15 and 16, all illustrated in Fig. 10.

The conflicts observed in cases 06 and 15 have the same reason: technique (b) pointed to an error which does not exist in fact. It is possible to say that it happened because of the measurement of the distance used to evaluate if the holes are obstructed by clips in the second algorithm. The length which was measured to allow the distinction between a misplaced

Electrical connector #06 Electrical connector #15



Electrical connector #16

Figure 10. Cases in which the correct detection were only possible because of the use of three algorithms together. The highlights represent where the error shown in Table 1 occurs.

clip and a correctly placed one has a measurement uncertainty and in both cases the measured value is located into the doubt region. Considering that this detection failed, it is interesting to evaluate again this distance in order to improve the performance of technique (b).

Finally, case 16 illustrates the only problem observed in technique (a). In this case, the diameter found by the algorithm was smaller than the measured one as the minimal correct diameter of the box holes. Since the clip is correctly assembled, the same consideration given to electrical connectors #06 and #15 applies to this case.

## IV. CONCLUSIONS

This paper proposes the use of VS to inspect the disconnection of the stator power cables inside the electrical connector, a common defect of electric motor stators. Three image processing techniques were developed to work redundantly, enhancing reliability. A test rig has been projected and built in order to test the vision system. A case study with 20 electrical connectors was executed achieving 100% correct indications. Even though the number of connectors under analysis was relatively small, tests were repeated under different conditions and the results remained the same. Next steps will be oriented towards validating the proposed vision system in an industrial production line.

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