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Anomalous corrosion phenomena observed on electrovalves of coffee espresso machines

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ABSTRACT

The domestic coffee machines market has widely expanded in the last five years. The core of these machines is an electro-pump that allows the correct water distribution. In this paper a root cause failure analysis was conducted utilizing some electro-pumps samples taken from a corroded batch. Several examinations were carried out in order to identify the root cause of the failure: visual examination, SEM-EDS analysis and microstructural characterization. The corrosion phenomenon is located at the piston-spring interface. As result of the examinations carried out, it has been possible to identify that the corrosion mechanism is due to different interacting factors: high chlorine concentration, potential dynamic difference between piston and spring materials, material sensitization and iron-manganese bacteria growth.

1. Introduction

Nowadays, domestic coffee machines are quite diffused worldwide and in the last five years their market has widely expanded, especially in Asia and North America [1,2]. Good mechanical properties, corrosion resistance and food-compatibility, represent the fundamental requirements ruling the correct choice of the materials that usually lead to the application of stainless steel grades. However, the water conditions (in term of hardness, ions concentration and electrical conductivity) may cause corrosion on the coffee machine devices. Therefore, a correct component design and a careful material selection are key activities to fulfill a reliable system.

One of the most important devices in a coffee machine is represented by the electro-pump, needful to deliver water at the correct pressure in order to brew a perfect *espresso*. The component analyzed in this work (Fig. 1), is composed by an electro-pump built by ferritic stainless steel encapsulated in a polymeric case (thermoplastic elastomer).

When a magnetic flow is induced by the inductor excitation (A in Fig. 2a), the ferritic steel piston (located within the hydraulic body) allows the pump to trigger, so the water flow can start from the tank to the boiler and then to the coffee capsule inserted in the machine.

The electro-pump main parts (Fig. 2b) are: the thermoplastic elastomer case (B), the ferritic piston (C) and the upper and lower austenitic springs (D and E).

Pistons are usually made of either AISI 430FMo (X6CrMoS17/EN 1.4105) or X6CrMoS19-2 (EN 1.4114) ferritic stainless steels (the only difference between these two steel grades is the higher molybdenum concentration featuring AISI 430FMo). Both these grades assure good corrosion resistance when applied in drinkable water with low chlorides concentration, cool and diluted organic acids solutions, cool alkaline solutions, saline solutions without chlorides and no-chloride soap solutions [3,4].

The upper springs are generally made of AISI 302 (EN 1.4310/X10CrNi18-8) austenitic stainless steel and the lower springs are made of AISI 316 (EN 1.4401/X5CrNiMo17-12-2). These two austenitic steel grades offer good corrosion

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Fig. 1. Examples of electro-pumps sampled from the batch and affected by significant corrosion problems.

resistance, especially against the pitting corrosion phenomena [3,4]. The chemical composition of the steel grades applied for the studied components are precisely defined in the international technical standards (Table 1).

At the end of the production route all the valves were tested in a hydraulic circuit (filled by water and passivizing solution) to determine the water flow rate that they can grant. The water characteristics without passivizing solution are listed in Table 2. Before warehouse storage the pumps have been filled by passivizing solution of water and sodium silicate (15 mg/l) that is able to maintain and control the acidity in a range between pH 8 and pH 9. After the inspection tests some valves are stocked at warehouse storage for several months, while several other valves are mounted by two weeks and they immediately begin to work. A surprising phenomenon has been observed: the valves mounted in few weeks do not point out any corrosive evidences, whereas the ones stoked for several months show significant corrosive phenomena.

2. Experimental procedure

In order to identify the causes responsible for the corrosion phenomena pointed out on the electropump pistons, different samples were investigated (Fig. 3).

Both pistons and springs are observed by stereomicroscope (SM) and scanning electron microscope (SEM) to identify the oxide layer morphology and its chemical composition. Scanning electron microscope is Carl Zeiss AG EVO 50 XVPW filament, equipped with Inca Oxford instruments EDS and BSE probes. The working distance used to analyze samples was 15 mm, the voltage was 20 kV and the current 125 pA. The pistons were also observed by optical microscope (OM) in order to identify their microstructure. Thus, samples were etched by aqua regia reagent [5] and electro-etched in 10% oxalic acid solution to highlight the possible chromium carbide precipitations [5]. In order to define the pistons and the springs polarization curves, different tests have been performed. All tests were performed at 22 ± 2 °C. In electrochemical tests a three-electrode cell was employed: the platinum reference electrode is featured by an area of 3.7×10^{-3} m^2 and saturated by silver–silver chloride (Ag/AgCl). The working electrodes are constituted by AISI 430 for characterizing the ferritic stainless steel while for the austenitic stainless steel AISI 316 was used. The working electrodes are featured by an average area of 2.5×10^{-4} m^2. The working electrodes were cleaned by ultrapure water and dried in cold air jet before the realization of electrochemical trials. The HCl concentration was set at 1 mol/l. The curves of anodic and cathodic potentiodynamic polarization have been obtained by 1 mV/s scan rate.

3. Results and discussion

The visual inspection pointed out that significant corrosive layers interest the pistons, especially in the inner part and in the contact areas with the austenitic springs.

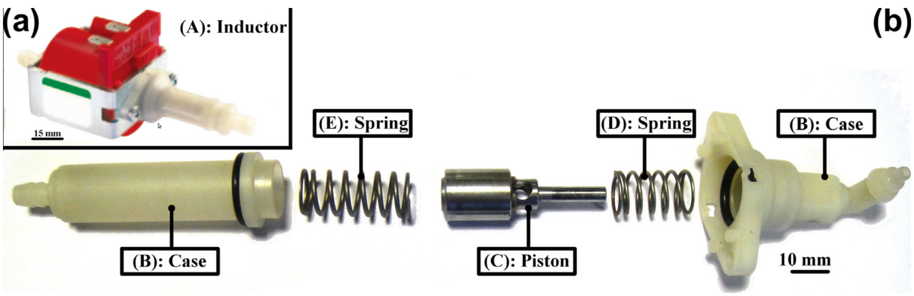

Fig. 2. Main parts composing an electro-pump system: (a) electro-pump assembled with external inductor; (b) pump internal components.