OPTIMIZING ROBOTIC TOOLS FOR WIRE CUTTING AND CRIMPING

A.Tasora, M.Silvestri
Università degli Studi di Parma
Parma, Italy,
tasora@ied.unipr.it, silve@ied.unipr.it

Abstract

This research describes the development of compact and efficient tools which can be used by a 4-DOF robot during an automated process aimed at the building of heating coils. Resistive wires must be cut and crimped into small connectors at a fast pace, with extreme repeatability and reliability. We designed two special tools for the end effector of a parallel-kinematic robotic device, exploiting a compact and lightweight design.
Wire cutting has been obtained by means of two custom blades. A test bed has been build in order to investigate the optimal shape of the blades, hence minimizing the actuating force and wear effects. A new cutting method has been proposed and a final cutting tool has been designed and mounted on the robot.
Crimping the resistive wire into miniaturized connectors required the development of small, yet stiff, pneumatic crimping pliers.
The cutting tool and the crimping pliers have been mounted on a single multifunctional end-effector. The robot successfully performed the high-speed tests, showing the high performance of the tools.

Keywords
Robots, parallel kinematic, automation, heating coils, wear, pliers, nippers, end effectors, cutting, crimping

1. INTRODUCTION

Wire coils are widespread components used in hair dryers, toasters and similar devices. Automated assembly processes for these products may be somewhat difficult because coils are made of thin resistive wires wrapped around oddly shaped insulating mica plates. Metallic connectors for the ends of the coils are often mounted on these mica plates, while advanced models may embed also additional electrical components such as thermal emergency switches, diodes and capacitors.
Given the small size of these parts, their flexibility and the uncertainty of their position, the task of cutting the resistive wires and the crimping of their ends into miniaturized connectors are critical phases of the automated assembly process.
In this paper we present a multi-functional tool for a robot which assists the assembly line of a complex heat coil for hi-end hairdryers, whose design exploits a triple-wire, triple-circuit wiring wrapped into a patented coaxial configuration supported by 12 interconnected mica plates (see Fig. 1).

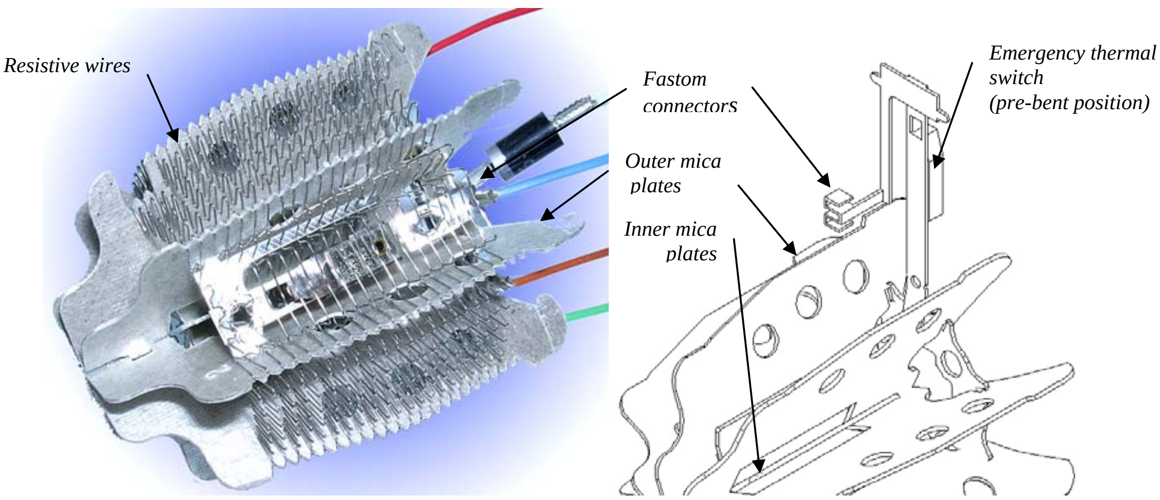

Fig.1 : Heat coil to be assembled (photo of final product and schematic picture, without wire)

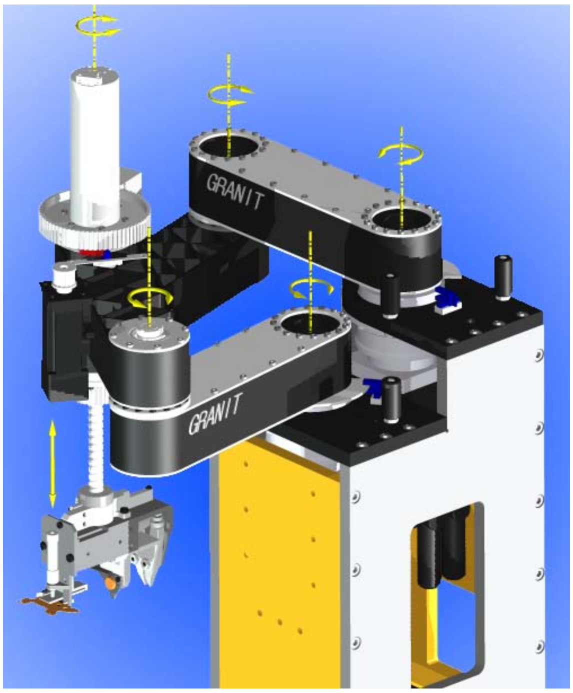

Fig. 2: The *GRANIT* parallel-kinematics robot, which has been built for this specific application

Because of the many operations needed to assembly this model of heat coil, at an early production stage the assembly process was partially automatic and partially assisted by an operator. Among the tasks of the operator there were the repetitive operations of cutting the wires of the three circuits with a nipper (two ends for three wires, that is six cuts per product) and crimping the wire ends into metallic connectors using hand-operated pneumatic pliers (four crimpings per product in total, since the three wires are crimped into a single connector at one end). The process was lengthy and not precise, so a full-digital-authority automation process has been studied and implemented, requiring no human supervision.

The main device in the new automated assembly line is a custom robot, which has three main tasks:

- it must be able to pick mica plates of different sizes from different dispensers, and mount them into the rotating shaft which will wrap the wires,
- it must cut the wires at the beginning and at the end of the cycle, in six different positions,
- it must crimp the wire ends into the four connectors, in four different positions.

Since the parts are very small, no positioning errors can be tolerated. Meanwhile, the motion of the robot must be fast enough to allow high paces in coil production. For these reasons we designed a custom parallel-kinematics robot, called *GRANIT* (see Fig. 2), which has some special features:

- because of the parallel kinematics architecture, the robot is very stiff and precise, even using low ratio motor reducers: we experienced that repeatability is as good as 0.01mm,
- stiffness is increased thank to the adoption of light-alloy honeycomb structures for the arms and special cross-cylinder thin-section bearings,
- the *GRANIT* robot has 4 degrees of freedom hence acting like a *SCARA* robot, but its design is lighter than a *SCARA* because the former has two motors fixed on the truss while the latter must carry a motor on the arm for elbow rotations: this means that our design exploits a low inertia and high accelerations (over 20 m/s^2),

In order to exploit the high dynamical properties of this robot, the end effector had to be as light as possible: this requirement enforces a constraint on many design solutions. Also, the end effector had to be very compact in size, either because the working volume of the robot is small (as for most parallel-kinematics machines), either because the working volume is cluttered by many other devices that are not illustrated in this paper.

Weight and size limits constrained the design of the end effector, especially considering that it had to perform three tasks: picking, cutting and crimping. In the following sections we will focus on the last two.

2. WIRE CUTTING

Resistive wires are usually made of special austenitic alloys, most often NiCr or NiCrFe alloys, sometimes called *Nichrome alloys*. In our case, we took into consideration different wires with different chemical composition, because various models of heat coils are under production, depending on 110V/240V operating mode or total power (up to 1700W). Depending on the model, the wire diameter can range from D=0.20mm to D=0.25mm, while the material can be a Nichrome alloy like the *Nicrothal™ N40* (35%Ni, 20%Cr, Fe balance) or similar.

In the previous manual assembly process, these wires were cut by simple nippers.

Despite pneumatic nippers are already available on the market, even with flanges for easy mounting on robot effectors, we decided not to use this solution for three main reasons. First of all, pneumatic pliers are mainly targeted at cutting small plastic parts or soft metals (copper wires), while Nichrome alloys can be quite hard: in some cases the Vickers hardness can reach HV250. Second reason is that nippers do not guarantee that the cut always happens: if the blades of the nippers are worn or dented, the wire will be simply trapped in the closing nipper, so it won't be cut completely and this will cause the assembly process to stop later with unpredictable entanglements. Last reason is that commercial pneumatic nippers are too heavy to be mounted on our end-effector, which moves on high-speed trajectories.

For the reasons above, we developed a solution based on a compact scissor-like mechanism. In fact, scissor blades are more reliable in cutting this kind of wires because a sensor can detect if the scissor blades has been closed completely. If the wire cannot be cut, either because of insufficient force or because the blades aren't sharp anymore and the wire gets trapped between them, the sensor can quickly detect the emergency situation.

Most important, our scissor blades have been built with a design which allows easy dismounting for periodic maintenance: using a grinding machine to remove a 0.1÷0.05mm flat layer from the contact faces, worn edges can be quickly repaired. On the other hand, most nippers would require the entire replacement of the blades.

To perform a correct dimensioning of the scissor, we built a test bed which provided experimental results for the cutting force. We experienced that for a wire with diameter D and ultimate tensile strength σ_s the normal force $F_\perp$ to be applied to the blade for cutting the wire is approximately:

$$F_\perp \geq K \frac{\pi D^2 \sigma_s}{4} \tag{1}$$

where we found that K is in the 0.55÷0.7 range and σ_s=675 N/mm^2÷800N/mm^2 for most NiCr or NiCrFe alloys. When K=0.58, equation (1) leads to the theoretical values which can be obtained by applying the straightforward Von Mises-Henky failure theory for pure τ_{xy} shear of a cylinder, that is:

$$\left(\sigma_x - \sigma_y\right)^2 + \left(\sigma_y - \sigma_z\right)^2 + \left(\sigma_z - \sigma_x\right)^2 + 6\left(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2\right) \geq 2\sigma_s^2$$

For example, a *Nicrothal™ N40* wire with diameter D=0.24mm and tensile strength σ_s=675N/mm^2 requires, at least, a cutting force $F_\perp$>18N. From these results we designed a very compact scissor mechanism, as depicted in Fig.2, which requires a small pneumatic cylinder with 6 bar of operating pressure and diameter ∅=10mm (providing a cutting force up to $F_\perp$=60N on the wire).

Interesting enough, we discovered that the optimal cutting angle of the blades is about 10°. Also we experienced that implementing a 'saw' or shearing effect between the blades (ex. leaving the rotation axis a bit on the side) does not have appreciable positive effects.

To avoid premature wear of blades, special care has been paid in choosing the proper material. Two choices proved to be reliable: pre-hardened high-speed-steel (cobalt-molybdenum DIN HS2-9-1-8) or pre-hardened cold-cut steel (K110, DIN X115CrMoV12-1). Both steels have extreme hardness after hardening: HRC>65, HV>800.

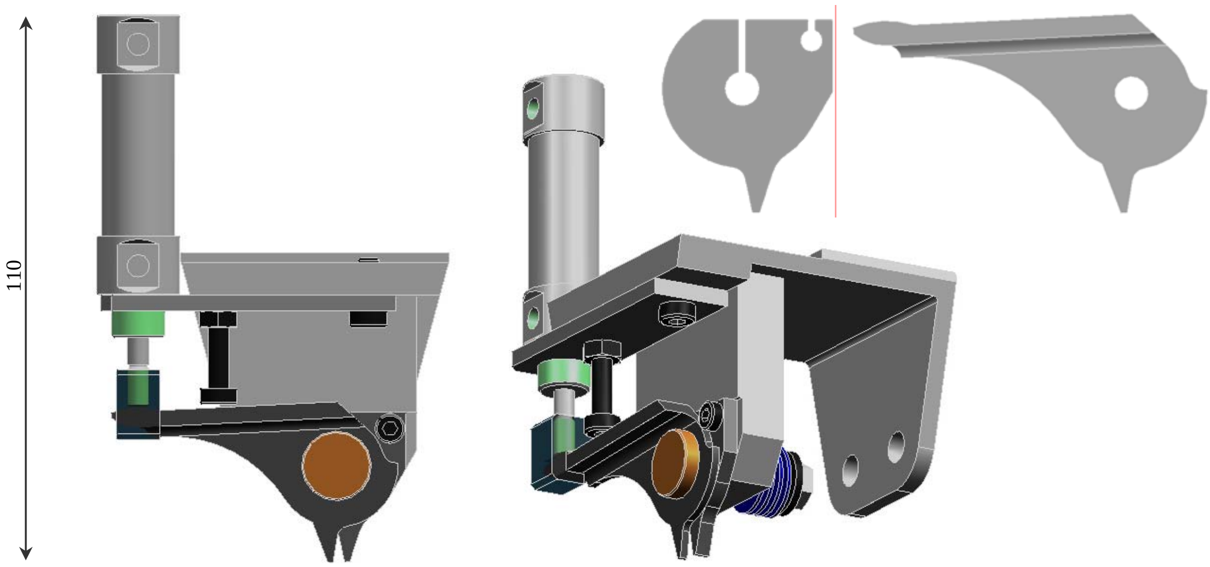

Fig.2: Wire cutter. Up right, closeup of EDM cutting path for scissor blades.

Since these hardened alloys cannot be cold-machined, the blades have been cut using *wire electro-discharge-machining* (EDM), a slow but very precise process. Complex profiles can be cut effortlessly with EDM: this helped us to obtain the blades from single-profile continuous cuts (no holes), where the movable blade also integrates a simple conjugate-cam mechanism for coupling it to the double-effect cylinder (Fig.2, right).

3. WIRE CRIMPING

Crimping of resistive wires into miniaturized connectors is a matter of squeezing a thin "C" shaped strip of metal around the end portion of the wire. The metallic connectors are usually made of tin-plated steel foils, with thickness up to 0.8mm.

Previously, the manual assembly cycle used commercial hand-operated pneumatic pliers to perform this task, using a very high operating force to avoid the risk of leaving the wire a bit loose in the connector. In fact, given the high temperature and the hairdryer-induced vibrations, the contact must be as stiff as possible, otherwise the electrical resistance or the safety of the coil may be affected. However, this conservative approach for the crimping force lead to many structural failures in pliers, as can be seen in Fig. 3.

Fig.3: Structural failure of old pliers

For this reason we built an experimental device which helped us to understand the lowest admissible force for the crimping operation. Many tests have been performed, and we obtained that a safe and reliable crimping could be obtained with a force of F_c=500N. This value depends on the shape and material of the connector, of course. Beyond this F_c value there are no benefits. We also experienced that good crimping may happen also for forces as low as 0.7 F_c , but in these cases the wire can be extracted from the connector if strongly pulled.

On the basis of these experimental results we designed a pneumatic crimping tool which can exert a maximum

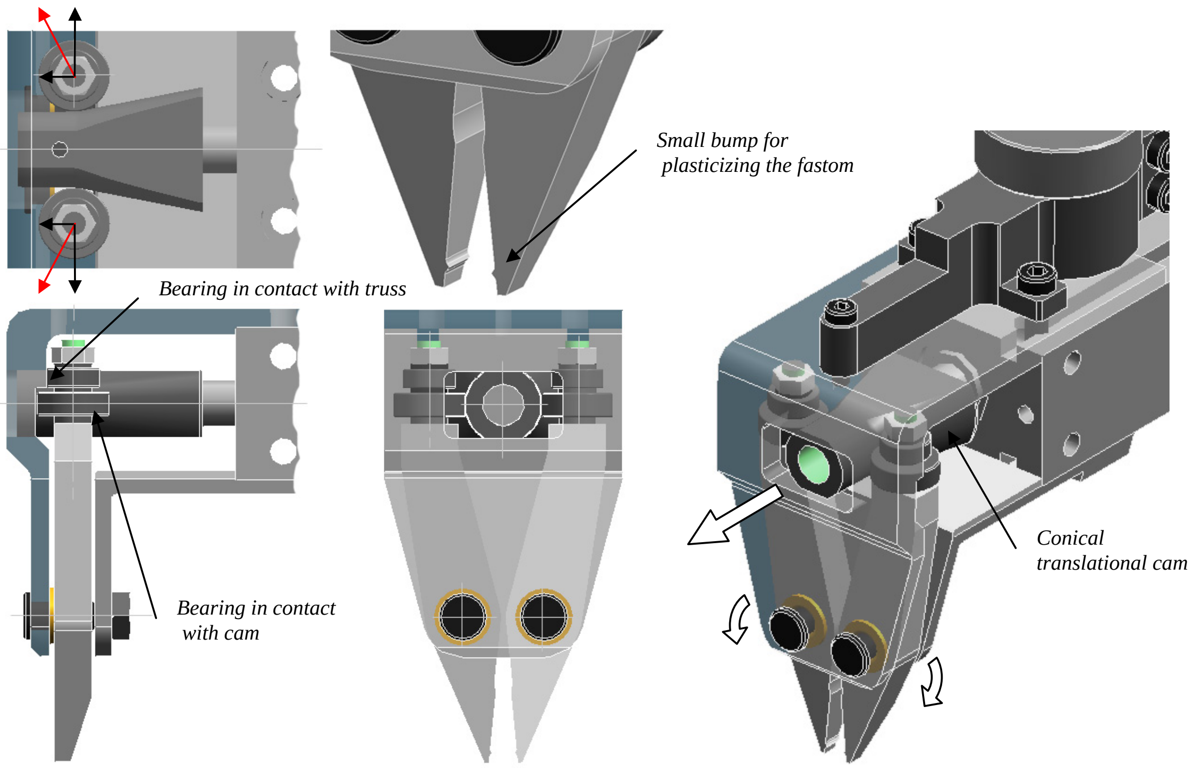

Fig.4: The pneumatic plier for wire crimping

force of 1000N when operating at 6bar. Thank to a pressure regulator it can obtain lower forces, as required.
The crimping tool has a novel kinematic scheme (see Fig.4) exploiting a 90° turning of force transmission, starting from a compact horizontal cylinder, going through a conical cam-rocker mechanism, then ending with the rotation of the vertical pliers. This was mandatory because the vertical space was very limited. In sake of the least stress of structures, there are two small auxiliary bearings which avoid that horizontal forces coming from the conical cam may bend the pliers forward (see Fig.4, left).
Because of constraints on sizes and masses, the small pliers have been optimised both via experimental tests and FEM software. The proposed materials (a maraging steel ISO X2NiCrMo18-9-5) can bear the computed stresses and can withstand fatigue for an infinite life.
Note that the rectangular body of the pneumatic cylinder have been used also as a truss for the entire effector, including the cutter and the picking grip. This saved some mass: the complete effector weights less than 1.5kg.

4. OTHER RESULTS AND FUTURE DEVELOPMENTS

As shown in Fig.2, on the right, we used a spring to keep the two blades of the cutter in strong contact. This is needed otherwise, if no contact is strictly enforced between the two flat surfaces, the wire may be trapped between them. However we experienced that for high-speed motion of the blades, this contact force is less mandatory. This is especially true if the rotation blade has a non-negligible mass (for a tenfold increase in mass, we could do without the spring). Among the possible justifications of this effect is the fact that, for high cutting speed, the trapping of the wire between the blades would require the system to undergo strong acceleration peaks, and this would imply also large inertial reaction forces, especially in case of blades with large masses.
We also experienced that mica powder (mostly silicate particles) easily saturates the environment where the robot operates. Oil and grease worsen the situation. This can be dangerous because of the pronounced abrasive effect of mica: most metallic materials, including hardened steels, may undergo wear because of these fine particles. For this reason, it may be compulsory to seal most mechanisms in over-pressurized casings.

5. CONCLUSIONS

We designed, built and tested a multifunctional end effector for a 4-DOF parallel-kinematics robot. Special tools have been studied for the tasks of wire cutting and wire crimping, in aim of the lowest mass, smallest size and highest reliability. By means of experimental tests we obtained data about the correct dimensioning of the cutter and the crimping pliers. The robot successfully performed high-speed tests, demonstrating the good performances of the tools.

References

[1] Righettini,P., Tasora,A., Giberti,H.: “Mechatronic design of a 3-DOF parallel translational manipulator”, *RAAD 2002*, 11th Workshop on Robotics in Alpe-Adria-Danube Region, 30 June - 2 July 2002, Hungary

[2] Righettini,P., Tasora,A., Giberti,H.: “Simulation of Pneumo-Mechanical System in a Multibody Environment”, *VENTIL*, ISSN 1318-7279, pp.79-83, June 2003, Slovenia

[3] Beer,F.P., Johnston, E.R., DeWolf, J.: Mechanics of Solids, Ed. McGraw Hill (3rd edition)

[4] URL: *http://www.kanthal.com* , heating alloys datasheet.

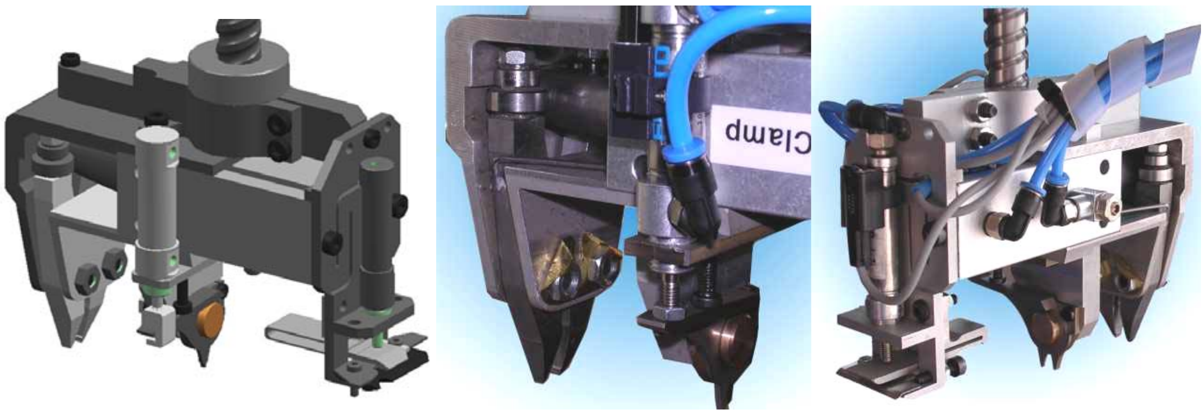

Fig.5: Full assembly of the end effector and first prototype.