Improving Robot Efficiency to Reduce Energy Consumption

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Introduction

When an industrial robot at ambient temperature is powered up, a warm-up cycle may be required to bring the robot to a thermally stable working condition. Without such a warm-up cycle, temperature-induced dimensional distortion [1] may seriously affect the positioning and orientating capabilities of the robot. Similarly, if a robot workcell goes offline for any number of reasons such as unexpected maintenance, material or tool changes, a short warm-up period may be needed to restore a steady state condition.

Thermal instability, which causes the dimensional distortion, arises from losses in the robot motors and gearboxes. It has been reported [2] that in some applications where a precise trajectory must be followed, a warm-up of as much as two hours of continuous motion, at 100% motor speed, through the reachable workspace may be required to reach steady state. Such warm-up cycles represent a potential loss in productivity and an un-necessary consumption of energy.

Consider a modest assembly line of 15 small payload (15 kg) robots each with an installed motor capacity (maximum energy consumption) of 3 kW. The average power consumption at average power usage of each robot is 1.2 to 1.5 kW [3, 4]. If the robots work continuously for three, eight-hour shifts each day (45 robot shifts) with an overall efficiency of 98% [5]; then, roughly 1 robot will be out of service for one shift each day. During the unloaded warm-up cycle approximately 1 kW is consumed. If a one-hour warm-up period is required, there will be an un-necessary energy consumption of 1 kWh each day or 365 kWh each year. This corresponds to two weeks of energy consumption for a typical North American family [6], or that of a small village of 40 for a year in the developing world [7]. However, for a line of 15 large pay-load robots, the unloaded consumption per robot is approximately 10 kW and the warm-up cycle time may be 3 to 5 hours [2]. In this case there is an un-necessary energy consumption of 18,250 kWh per year.

According to the Ontario Energy Board [8], the cost for non-residential consumers is C$0.05 /kWh (up to 750 kWh) and C$0.059/kWh for consumption exceeding 750 kWh. Energy wasted in the warm-up cycle for the hypothetical large payload robot line is $1070. If a plant has multiple assembly lines or multiple facilities, the total cost will be much larger. There is also the associated loss of production that occurs during the warm-up cycle. For high performance production lines the economic consequences may be significant.

Objective

The goal of this work is to develop a model-based control algorithm to compensate for the temperature-induced deformation associated with the warm-up period. For any assigned trajectory and load, the control algorithm will relate robot geometry to temperature changes, material behaviour, and the contribution of each motor and gearbox.

A single-link system comprised of one motor and one link (6061 Aluminum in the T6 condition) was attached to the shaft of a servo motor in a manner similar to that seen in small pay-load industrial robots. The motion of the apparatus was controlled by the wrist motion (sixth axis) of a Thermo CRS A465 robot.

The behaviour of the slender link, in which longitudinal deformation dominates, is determined as follows: experimentally with a charge-coupled device (CCD) camera [9] for measuring dimensional changes and an infrared camera [10] for measuring temperature; analytically using equations based on the coefficient of thermal expansion; and numerically with coupled thermo-mechanical FEA [11]. This three-pronged approach allows multiple cross-checking of behaviour and, for example, identified that the camera also requires a warm-up cycle to prevent spurious thermal-deformation results of the camera and its mount from being attributed to the link.

Figure 1 shows a typical result in which the location of the centroid of the laser spot in the longitudinal (x-axis) direction is plotted over the 190-minute period. Initially at room temperature, the linkage was heated indirectly from the output shaft, which was wrapped with and heated by an insulated flexible heating pad. The dashed oval shows the transient period, where the temperature-induced deformation occurred during the first 32 minutes. The linkage at steady-state is 9.5 μm longer than its original length. Clearly there is a need for a warm-up cycle in even this simple mechanical system.

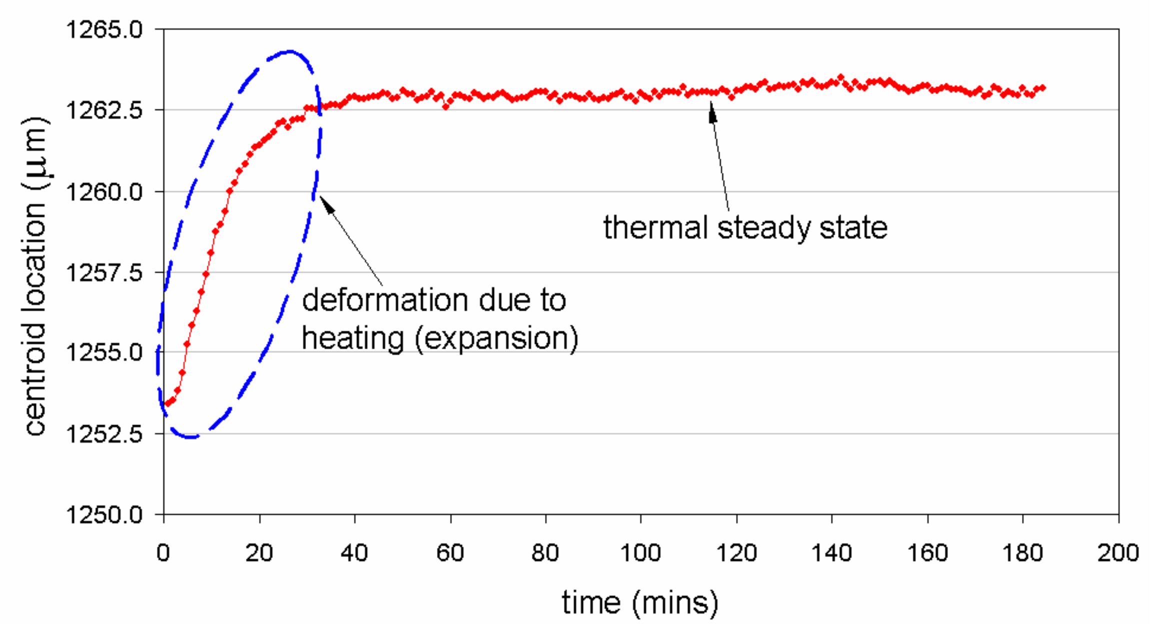

Figure 1: Experimental results from single-link system.

Next Steps

The single-link experiment and its corresponding analytical and numerical predictions, suggest that it is possible to develop a simple predictive algorithm for industrial applications. A multi-link experiment is now under development. Further work is needed to understand the material properties and thermal boundary conditions in the experimental, analytical and numerical models.

With a sufficiently accurate controller algorithm, the repeatability of the robot can be improved along with the positioning accuracy of the robot. It is expected that greater positioning accuracy can be achieved in this way than can be achieved through calibration alone. This improvement in manufacturing efficiency will allow the robot to perform productive work during the warm-up cycles and in doing so, increase productivity and reduce un-necessary energy consumption.

References

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