using available data, pulse current and pulse duration can be selected in terms of minimizing total machining time. A pulse efficiency analyzer measured the time duration of effective erosion sparks and a differential transducer tracking the downfeed monitored the machining condition. A software package was developed to carry out decision making by applying adaptive control constraint and simple, one-dimensional search. A general purpose mini-computer handled data transfer, decision making, and output adjustments of servo rate and off-time to the machine. Comparison was made between manual control and computer control. It demonstrated the potential of computer control and computer control. It demonstrated the potential of computer control which approached stable machining during shorter time periods and completed the entire machining with a smaller total machining time. Further, basic research is needed to explore the interrelationships between process variables and process performance. This will be conducive to a better algorithm for off-line process planning and a more effective decision table for on-line computer control. The ultimate goal is to have EDM process fully automated with optimal efficiency.

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References


**DISCUSSION**

F. Van Dyck

1. On Adaptive Control in E.D.M. In Dr. Mitchell Tseng's paper, "manual control" does not mean an operator has to control the electrode downfeed manually. E.D. machines are equipped with a servo system for electrode downfeed. In most feed control systems a pre-selected set-voltage is subtracted from the average voltage between electrode and workpiece. When the result of this subtraction is positive, the electrode is moved towards the workpiece (too few sparks occur which results in a relatively high voltage between electrode and workpiece). When a negative result is obtained, the electrode is retracted (short circuits yield low work voltage). This feed control system continuously searches for optimal electrode-workpiece distance when other machining parameters are changed. Besides the feed control system, modern E.D. machines are also equipped with an ar interruption device. "Arcing" in E.D.M is the concentration of subsequent sparks on the same location on the workpiece damaging the surfaces. Arc detection systems measure ignition delay time or high frequency variations of the pulse current, or impedance of the forward gap during off time. Arcing is interrupted by retracting the tool or changing the pulse train characteristics. Therefore, almost all industrial E.D. machines are in essence "first level" adaptively controlled.

Machines with first level AC require an operator for in-process adjustments of the feed control set-voltage and the pulse interval time (off-time). For usual electrode and workpiece materials, E.D. machine manufacturers supply tables with recommended values for these two parameters. For unusual electrode materials or when special shapes have to be machined, data are not available. In such cases an experienced operator will only be able to find a suitable machine setting by "trial and error" search while machining. Such a search was undertaken in the "manual control" experiment described by Dr. Tseng.

The mini-computer control system described by Dr. Tseng is an advanced "first level" AC system. The electrode feed control is dominated by a higher level controller. Significant increase in metal removal rate is obtained in the tests. Unfortunately, one cannot judge upon the industrial value of the system because data are given on only four machine runs with the same electrodes and workpieces. The pulse efficiency sensing system (see formula 3) is a good input sensor but the metal removal rate sensor is questionable, especially in finishing operations, relative electrode wear becomes important and downfeed
increments are smaller than the resolution of the sensor. It should be mentioned that significant research contributions to first level AC in EDM are also made in Germany (T. H. Aachen, Professor Koenig et al.), Belgium, (K. University of Louvain, Professor Snoeys et al.), Switzerland and Japan. Better input and output parameters for minicomputers and micro processors are developed.

I would like to conclude this discussion on AC in EDM by suggesting that research into the "third level of adaptive control" should be started. This second level could also be called the "self learning machine level." An operator would only help the machine by inputting information about the things the machine can not know (geometry and material information). All first level adaptively controlled operations would be followed by the second level "brain" of the system that will guide upon the performance of the first level strategy. The strategy put forward by Dr. Tseng can be considered as one out of a whole set of strategies. Self learning EDM machines would investigate different strategies, select them and use them when appropriate.

2. On Productivity. In Dr. Tseng's work maximum productivity was obtained with maximum metal removal rate because process parameters such as pulse current, pulse duration and electrode dimensions were pre-selected. However, I would like to emphasize that a much larger set of strategies exists for increasing productivity of engineering and societal activities. In most cases, "doing things as fast as possible" is only a strategy for reaching sub-optima. It is also necessary for engineers to be concerned and contribute to the development of strategies for reaching the real optimal productivity of systems that fulfill the human needs.

I want to congratulate Dr. Tseng for the good results he obtained.

Author's Closure

The servo system for electrode downfeed in commercial EDM machines should be considered as feed-back control instead of adaptive control. It maintains the appropriate gap distance according to a preset voltage. It neither measures machining performance nor modifies machining parameters to approach optimum as does the term "adaptive control" defined in the introduction of this paper. Although there have been many attempts to develop AC systems in EDM, mostly in Europe and Japan, no working system consistent with the AC definition has been made public, at least when this experimental work was completed and reported [14].

As for sensing devices, the author agrees that a pulse efficiency analyzer will suffice for detecting instantaneous sparking conditions. However, the overall machining performance still has to rely on some kind of in situ direct measurements where researchers run into the same problem as tool wear sensing in conventional machining. Fortunately, the ratio of electrode wear and material removal remains rather constant when the sparking condition is under control; in other words, when pulse efficiency is satisfactory. The combined resolution of the down-feed detector and A/D converter used in this study is 0.001 in. (25.4 μm) which is compatible to the amount of downfeed in the 16-sec cycle time reported here. The electronic and computer technology are available now to achieve higher resolution if needed. Therefore, the combination of pulse efficiency analyzer and down-feed detector appears to be practical to provide the necessary information in describing machining performance without interrupting the machining operations.

The authors concurs that Artificial Intelligence (AI) or "self-learning machine level" (as Dr. Van Dyck indicated) might provide a solution in controlling typical manufacturing processes such as EDM with the complexity and stochastic nature involved. He also would like to point out that the AC system is an important step for achieving EDM with Artificial Intelligence. The ability to monitor on-line and record machining performance as reported here is instrumental in accumulating manufacturing experience. This experience can be applied to improve on-line control strategy as well as the off-line process-planning data bank.

The authors wishes to thank Dr. Van Dyck for stimulating this discussion to clarify the above important issues.