ISSN 1726-5479

SENSORS & TRANSDUCERS

11 vol. 16 Special /12

Intelligent Data Acquisition and Information Process Technologies and Their Applications

International Frequency Sensor Association Publishing

IFSA

Sensors & Transducers

Volume 16, Special Issue
November 2012

www.sensorsportal.com

ISSN 1726-5479

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Sensors & Transducers Journal

Contents

Volume 16
Special Issue
November 2012

www.sensorsportal.com

ISSN 1726-5479

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Sensors & Transducers Journal, Vol. 16, Special Issue, November 2012, pp. 152-160

www.sensorsportal.com

Sensors & Transducers

ISSN 1726-5479
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Development of a New Kind of Multihole Cylindrical Electrode Used for Electrical Discharge Milling

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Received: 11 September 2012 /Accepted: 11 October 2012 /Published: 20 November 2012

Abstract: In order to improve the flushing condition of the electrical discharge (ED) milling, a new kind of cylindrical electrode used for ED milling is developed, which has a central hole and different number of eccentric holes. Firstly, the principle of ED milling with multihole cylindrical electrode is introduced. Secondly, ED milling experiments are carried out with the multihole cylindrical electrode, effects of the hole number and the emulsion pressure on the process performance such as the material removal rate (MRR), the relative electrode wear ratio (REWR) and the surface roughness (SR) have been investigated. According to the analysis of the experiment result, it is found that the multihole cylindrical electrode is more efficient in ED milling than the conventional tube cylindrical electrode. Effect of single and multi-channel electrodes application on EDM fast hole drilling performance.
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Keywords: Electrical discharge milling, Multihole, Electrode, Process performance.

1. Introduction

Electrical discharge machining (EDM) is a non-traditional manufacturing method, which transform electric energy into heat energy [1]. Electrical discharge is established due to excitation of a pulse generator which produces square-shape pulses with adjustable on and off times, voltage level, and discharge current [2]. It is a thermal erosion process, and is not subjected to the mechanical properties of the material and the complexity of the geometry. As a non-traditional material removal process, EDM has long been widely employed in machining difficult-to-work electrically materials [3]. Materials of any hardness can be machined as long as the material can conduct electricity, EDM does not make any

direct contact between the electrode and the work piece, as a result, it can eliminate the effect of the mechanical stresses, chatter and vibration problems [4-6]. Traditional sinker EDM machine tools servo-control a single axis which takes a tool with a complementary shape of a required in the work piece, as a result, this technology needs a lot of time and cost to manufacture the complex tool; In order to get the desired work piece geometry, different stages and several tool are needed due to the tool wear during the sinker EDM. There are issues with effective flushing of the machining gap as well, when the sinker EDM is applied with a large frontal machining area or deep features, the bad flushing condition destroys the stability of the process, it also affects the machined surface and reduces the removal rate [7].

With the development of computer numerical control (CNC) and mathematics, the EDM got a enabled novel machining strategies such as planetary/orbital, one evolution of CNC contouring is electrical discharge milling (ED milling) [8]. Compared to traditional sinking EDM, ED milling needs less cost and time to manufacture tool as they use standard tool electrodes, and profit from the relative motion between the tool and the work piece, the ED milling get adequate flushing from the machining gap, and it is possible to employ jet flushing [8-10]. Some investigations have been done about the ED milling. M. Bayramoglu and A. W. Duffill [11] investigated the machining characteristics of 3D form work piece with the cylindrical tool, then one machining method was selected, and it showed the most beneficial results. G. Puthumana and S. J. Suhas [12] put forward a new kind of cylindrical tool electrode with peripheral slots, in order to provide more space for the dielectric flow for consequently improving material removal rate (MRR). M. Bayramoglu and A. W. Duffill [13] used some simple plate tools to generate the linear and circular 3D cavities, they got better surface integrity and less cost than the 3D form tools, however, process performances of those researches are not be improved significantly.

This paper describes a new kind of cylindrical electrode used for ED milling, which has multihole section to improve the flushing condition. Firstly, the principle of ED milling with multihole cylindrical electrode is introduced. Secondly, ED milling experiments are carried out with multihole cylindrical electrode, and MRR, REWR and SR are investigated.

2. Principle of ED Milling with Multihole Cylindrical Electrode

The schematic of conventional tube cylindrical electrode used for ED milling is shown in Fig. 1 (a), The tube electrode and the work piece are connected, respectively, to the negative and the positive poles of the pulse generator, the work piece is mounted on the XY-stage, the tube electrode does rotary motion driven by the spindle fixed on the Z-stage. The water-based emulsion is supplied through the electrode, and flows into the gap between the electrode and the work piece through the central hole of the electrode. During the ED milling, the electrode moves to the work piece, and the unremoved pin-shaped work piece decrease the flow area of the emulsion, as a result, it becomes difficult for the emulsion to flow into the gap, and the debris particles can not escape from the gap easily, some short-circuits appear, therefore the working conditions of the gap begin to deteriorate, the material removal rate decrease significantly.

The multihole cylindrical electrode is a new kind of electrode used for ED milling with eccentric holes distributing around the central hole uniformly, the schematic of the multihole cylindrical electrode used for ED milling is shown in Fig. 1 (b), the central hole is remained because of avoiding the zero relative velocity between the electrode and the work piece. Compared to the conventional tube cylindrical electrode, the eccentric hole of the multihole cylindrical electrode plays an important role in improving the working condition, the advantage of the multihole cylindrical electrode include: (i) when the electrode moves into the work piece driven by the Z-stage during the ED milling, the eccentric hole of the multihole cylindrical electrode will supply enough emulsion with less effect of the unremoved pin-shaped work piece, and (ii) when the electrode moves driven by the XY-stage, the eccentric hole will supply the emulsion to the front of the electrode in motion direction with the help of the rotation.

Altogether, the new multihole cylindrical electrode is efficient in diffusing the emulsion and preventing the debris from remelting on the surface of the work piece.

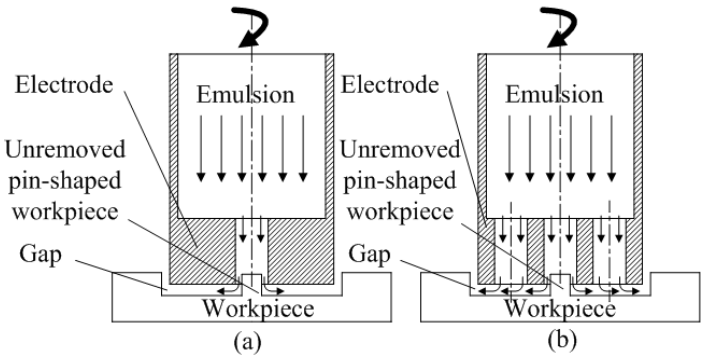

Fig. 1. Schematic of (a) conventional tube cylindrical electrode; (b) multihole cylindrical electrode.

3. Experiment Setup

3.1. Experiment Equipment

The photograph of the ED milling machine tool is shown in Fig. 2, which is designed by us based on the open architecture. The tool electrode is mounted on the main spindle which can rotate from 0 rpm to 2800 rpm with the help of an AC inverter. The work piece is fixed on the XY-stage. The pulse generator has a maximum capability of 75 A and 150 V, the emulsion supplying system can adjust the emulsion pressure in the range of 0-0.3 MPa with the circulatory pump controlled by an AC inverter, it also achieves the injection flushing via the rotary joint structure. The control system calculates the feedrate of the ED milling according to the average gap voltage.

Fig. 2. Photograph of the ED milling machine tool.

3.2. Multihole Cylindrical Electrode and Work Piece Preparation

During the experiment, the tool electrode is made up from round copper bar (length: 65 mm, outer diameter: 10 mm), the end of the round copper bar is finish turned and ground. Then, each hole of the multihole cylindrical electrode is machined by sinking EDM with the inner diameter of 2 mm. The photograph of the multihole cylindrical electrode with different number of holes is shown in the Fig. 3.

Fig. 3. Photograph of the multihole cylindrical electrode with different number of holes.

The material of the work piece is AISI 1045. The work piece is of size 50 mm × 30 mm × 5 mm, and cut by a WEDM machine tool, both of the top face and the bottom face are grinded.

3.3. Experimental Procedure

Theoretically speaking, the multihole cylindrical electrode can be more efficient in removing the work piece than the tube cylindrical electrode as the multihole cylindrical electrode can diffuse the emulsion and remove the debris efficiently, in order to prove the assumption and reveal the machining characteristic of the multihole, some experiments are carried out, during those experiments. Firstly, the multihole cylindrical electrode moves into the work piece driven by the Z-stage with the depth of 1 mm, secondly, the work piece does horizontal movement driven by the XY-stage with the length of 20 mm, subsequently, the multihole cylindrical electrode moves into the work piece again with the depth of 1 mm, after getting the position, the work piece does horizontal movement in the opposite direction of the first horizontal movement with the length of 20 mm, finally, the multihole cylindrical electrode does upward movement to a safe position.

Purpose of the study is to investigate the effect of the number of the hole and the pressure of the emulsion on the responses namely MRR, REWR and SR. Firstly, electrodes with different number of holes (from one to five) are used with a emulsion pressure of 0.2 MPa, then some electrodes with three holes are used during the experiment with different pressure of emulsion from 0-0.3 MPa, under the condition of 0 MPa, the work piece is sank in the emulsion to obtain stable discharging. Some machining parameters of the experiment are listed in Table 1. Weight changes of the electrode and the work piece after and before the experiment are measured using a precision balance (Model BS224S) with the accuracy of 0.1 mg.

Table 1. Machining parameters of the experiment.

Machining parameter	Value
Open voltage, (V)	140
Peak current ,(A)	75
Pulse on time, (μs)	400
Pulse off time, (μs)	300
Electrode revolution, (rpm)	2100
Electrode polarity	negative
Work piece density, (g/cm3)	7.85
Electrode density, (g/cm3)	8.90
Dielectric	water-based emulsion

3.4 Response Variables

MRR is expressed as the ratio of the volume of removed work piece during the experiment to the machining time:

$$MRR = \frac{(m_{mb} - m_{ma}) \Big/ \beta_m}{t}, \tag{1}$$

where, t is the machining time, β_m, m_{ma} and m_{mb} represent respectively the density of the work piece, the weight of the work piece after and before machining.

REWR is expressed as the volume percentage of the volume of the electrode wear to the volume of the removed work piece:

$$REWR = \frac{(m_{tb} - m_{ta}) \Big/ \beta_t}{(m_{mb} - m_{ma}) \Big/ \beta_m} \times 100\%, \tag{2}$$

where, β_t, m_{ta} and m_{tb} represent respectively the density of the electrode, the weight of the electrode after and before the experiment.

The SR is measured using a surface roughness tester (TR220, Time Group Incorporation, China).

4. Results and Discussion

4.1. Effect of the Number of the Hole on the Process Performance

Fig. 4 shows the influence of the hole number on the MRR, it can be see, MRR increases initially with an increase of the hole number, the highest MRR with three holes is 120 mm^3/min, about 2 times that of one hole, when the hole number is larger than three, MRR decreases with the increase of the hole number. This is because, the flow area of the emulsion increases with an increase of the hole number, the eccentric hole supplies massive emulsion without the effect of the unremoved pin-shaped work piece, the gap environment is improved, the discharging becomes more and more stable, thus, MRR increases correspondently, when the hole number is larger than three, the flow area becomes so large that the flow velocity around the central hole decreases, therefore, it became difficult for the debris to escape from the gap, then, the feedrate of the electrode slows down, as a result, MRR decreases.

Effect of hole number of the electrode on the REWR is shown in Fig. 5, Unlike the MRR, REWR decrease initially with an increase of the hole number, then REWR begin increasing when the hole number is larger than three, the reason is that, with the increase of the flow area, the discharging condition gets improved, as a result, the protective layer [14] on the tool electrode composed of the decomposition of the dielectric and work piece material gets thicker, thus, the protective effects of the deposition layer decreases the electrode wear. When the hole number is large than three, the discharging environment around the central hole gets worse, more and more short-circuits increase the electrode wear, the REWR increase.

Fig. 6 shows the effect of hole number of the electrode on the SR. Like the MRR, SR increases initially then decreases with the increase of the hole number, this is because, with the improvement of the discharging condition, it is more easy to form ionized bridges across the gap and result in less ignition

delay and the energy of single discharging increases, as a result, the crater gets larger, the SR increases, when the hole number is larger than three, the discharging condition around the central hole gets worse, the discharging becomes weaker and weaker, the carter gets smaller, SR decreases correspondingly.

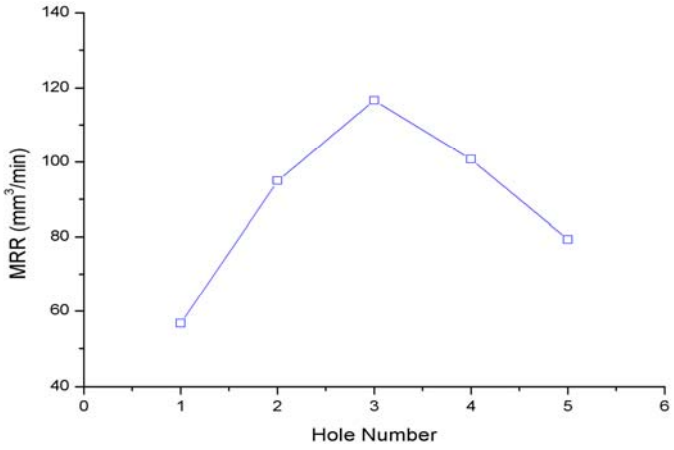

Fig. 4. Effect of hole number of the electrode on the REWR.

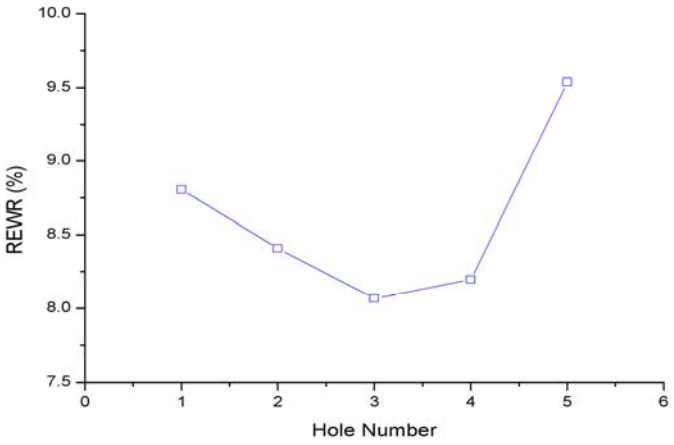

Fig. 5. Effect of hole number of the electrode on the REWR.

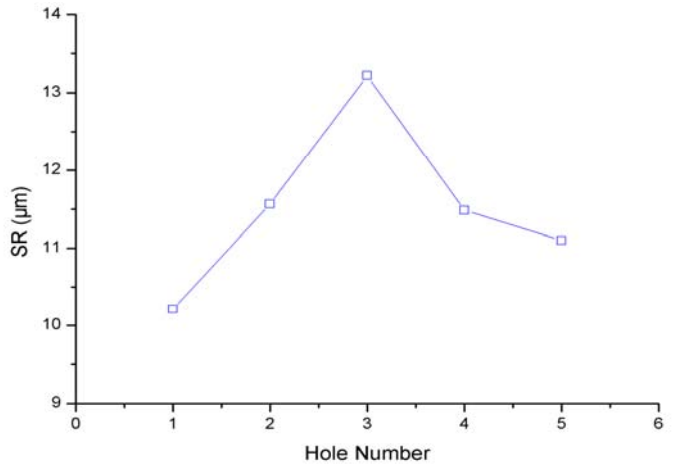

Fig. 6. Effect of hole number of the electrode on the SR.

4.2. Effect of the Emulsion Pressure on the Process Performance

Effect of the emulsion pressure on the MRR, REWR and SR are illustrated in Fig. 7, Fig. 8 and Fig. 9, respectively. MRR and REWR increase rapidly with the increase of the emulsion pressure, there are two main reasons for this. Firstly, with the increase of the emulsion pressure, the debris is easily flushed out [15], as a result, stability of discharging is improved. Secondly, during ED milling, the pressure affects the ionized bridge, with the increase of the emulsion pressure, the ionized bridge is compressed, and the energy density increases, thus, both the MRR and REWR increase.

Unlike MRR and REWR, SR decreases with the increase of the emulsion pressure, there are many reasons for this phenomenon, the main reason is the cooling effect of the emulsion, and the cooling rate of the electrode with large emulsion pressure is faster than the small emulsion pressure.

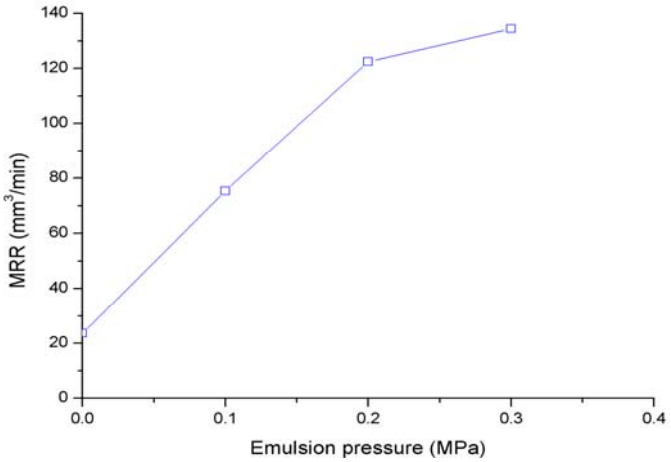

Fig. 7. Effect of emulsion pressure on the MRR.

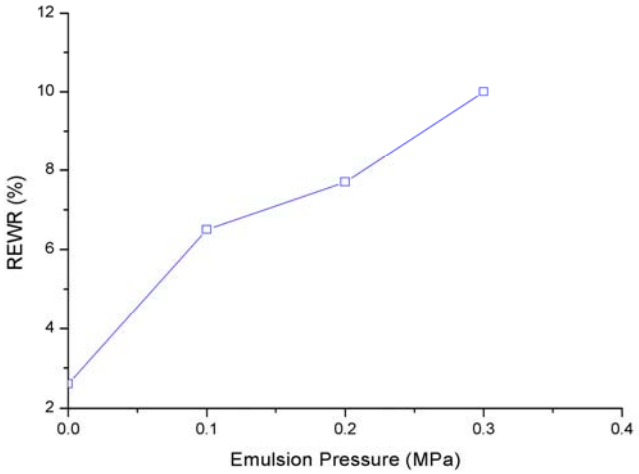

Fig. 8. Effect of emulsion pressure on the REWR.

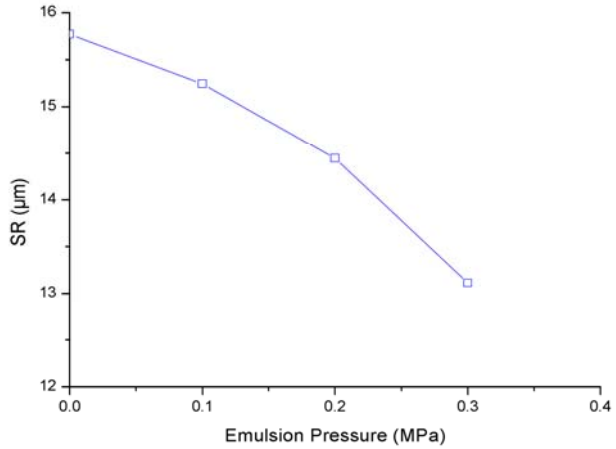

Fig. 9. Effect of emulsion pressure on the SR.

5. Conclusion

In this study, a new kind of multihole cylindrical electrode is developed, some experiments are conducted, based on the result, the following conclusions can be drawn:

1) The multihole cylindrical electrode can supply more stable discharging with certain condition than the electrode with one hole;
2) Compared with the electrode with one hole, the multihole hole can get high MRR and low REWR using the emulsion with 0.2 MPa;
3) When the emulsion pressure is 0.2 MPa, the multihole with three holes has the highest MRR, SR and lowest REWR, the increase of the hole number reduces the discharging condition around the central hole;
4) When the hole number of the electrode is three, MRR and REWR increases with the increase of the emulsion, while the SR decreases.

Acknowledgements

The work is partially supported by Science and Technology Development Plan of Qingdao City (Grant No.12-1-4-7-(2)-jch), Taishan Scholar Construction Project of Shandong Province (Grant No.TS20110823), Graduate Innovation Found (Grant No. 11CX06065A), Fundamental Research Funds for the Central Universities (Grant No. 11CX04031A), Thanks for the help.

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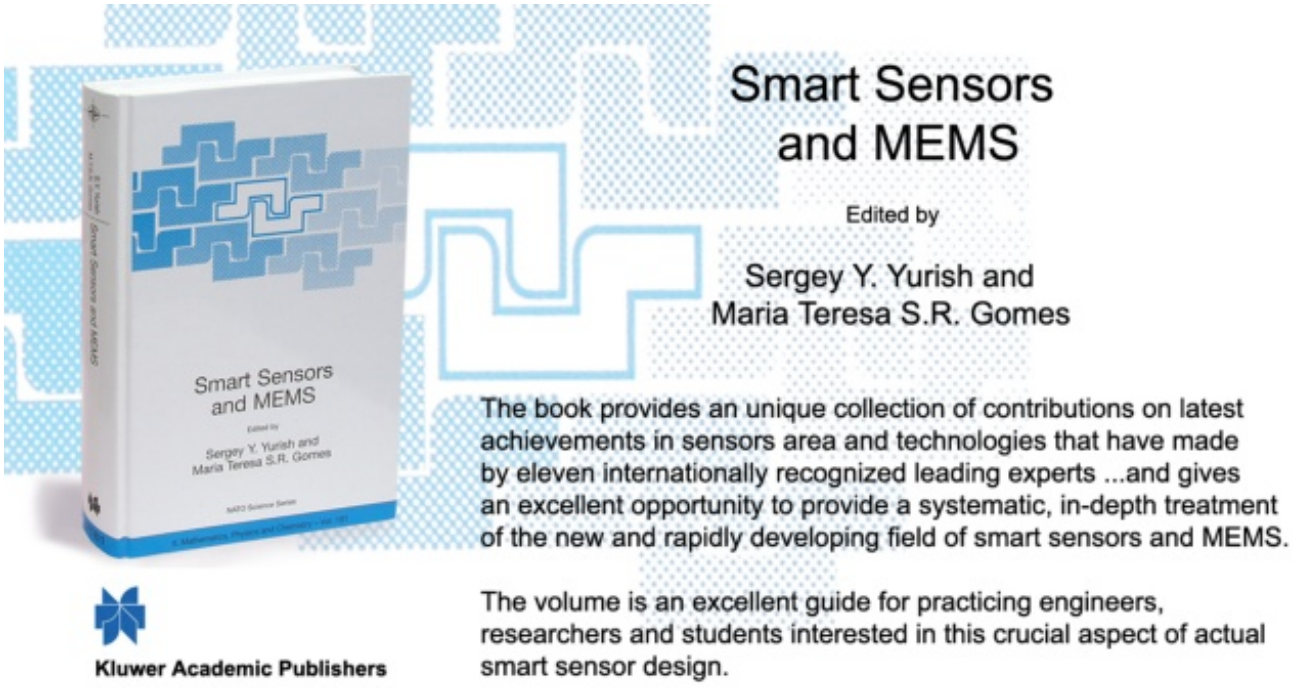

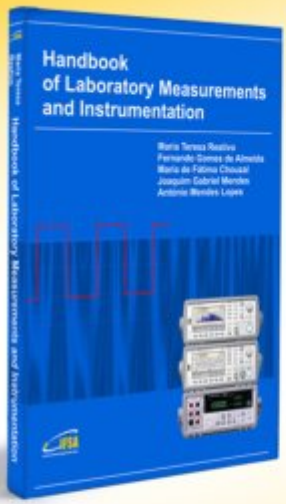

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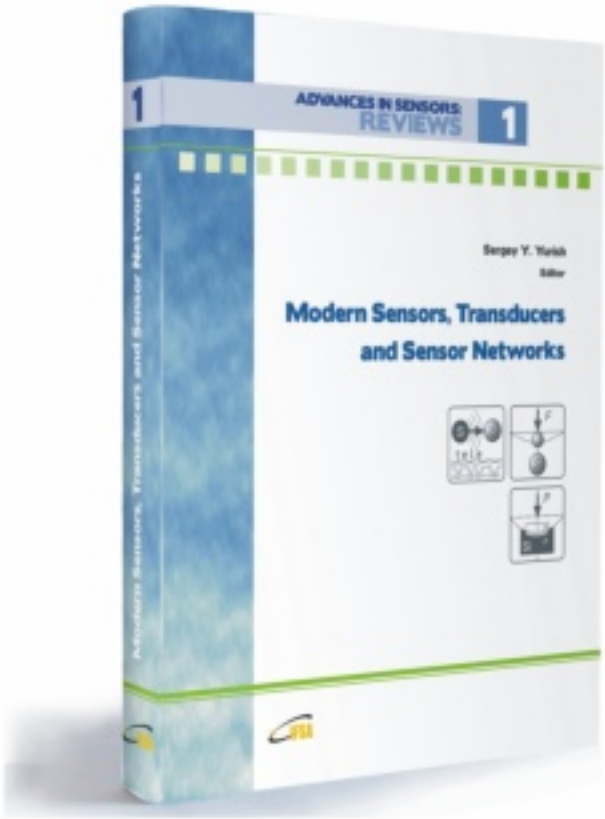

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