Article ID: 1003-6326(2004)01-0166-04

Metal particle's precipitation behavior in direct reading ferrography precipitator tube ①

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Abstract: A new metal particle monitoring instrument was developed by improving the traditional direct reading ferrography. The precipitation behaviors of sub-magnetic particles, magnetic particles, and the mixture of these particles were examined with the instrument. The results show that the precipitation behavior of sub-magnetic metal particles of copper and aluminum is not random as it was believed previously. The sub-magnetic particles show a distribution in the precipitator tube, almost the same as the deposition curves as the magnetic particles have. The deposition amount of particles is increased in the oil which consists of several different kinds of particles. On the base of these experiments, a new index used for the total quantity of wear was redefined.

Key words: fault diagnosis; oil analysis; sub-magnetic particle; deposition; monitoring

CLC number: TH 117 **Document code:** A

1 INTRODUCTION

It is nearly thirty years since the first direct reading(DR) ferrography was developed. This simple instrument is suitable for use at plant or depot level as a regular test for oil condition analysis. It can quickly get the results, and can automatically measure the density of deposited large particles compared with those of small ones. The oil sample is siphoned into a transparent precipitator tube that is placed between the poles of a magnet. The magnetic particles contained within the sample are deposited in the tube and measured at two specific locations. The equation of the motion of a particle in the tube is a complex function of its size, shape, magnetic susceptibility, density and the viscosity. However, the magnetic attraction force acting on the particle is approximately proportional to its volume and magnetic susceptibility. This makes the larger particles (those greater than 5 μm) deposit near the entrance of the tube while the smaller ones and sub-magnetic particles deposit further along the tube. With the two monitoring points of the DR ferrography, only two parameters are obtained, namely D_l which represents the reading of the larger particles greater than 5 μm in size, and D_s which represents the reading of the smaller particles up to 5 μm in size. Both D_l and D_s mainly relate to the magnetic particles, not to the sub-magnetic or non-magnetic particles[1-5]. In some cases, the information of the sub-magnetic particles is very helpful to predict the faults. However, it cannot be gotten by the simple DR ferrography. In view of this drawback, efforts were made to improve the DR ferrography. Additional four monitoring points are added to form the metal particles monitoring instrument(MPMI). The aim is to measure the sub-magnetic particles or non-magnetic particles with the four additional points. Therefore, a wider scope of deposition can be detected, and more information of particles can be obtained[6,7]. For example, oil from an engine may contains more sub-magnetic particles than that from a gear box, which contains more magnetic particles. The experiment results show that MPMI is very useful. The distribution of sub-magnetic particles of copper and aluminum is not random when deposited in the precipitator tube.

In this paper, a magnetic particle means that the value of the susceptibility is very large, while a sub-magnetic particle means that the value of the susceptibility is smaller. For example, the susceptibility of iron oxide (FeO) is 7200×10^{-6} (CGS) when the temperature is 293 K. The particles of iron oxide are magnetic. The susceptibility value for aluminum in an ordinary condition is 12×10^{-6} (CGS), and for copper is 5.46×10^{-6} (CGS) at 296 K[8]. The particles of aluminum and copper are sub-magnetic.

2 EXPERIMENTAL

2.1 Experiments of single particle

The experiments of magnetic particles were firstly done in order to compare with that of the sub-magnetic particles. These particles, including the follow-

① **Received date:** 2002-10-10; **Accepted date:** 2003-03-08

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ing particles used, were especially ordered from an institute in Beijing. Their size in length was less than 20 μm. The oil used in the experiment was hydraulic oil of No. 32. The concentration of particles was 100 mg magnetic particles per 100 mL oil.

Firstly, oil sample nearly 50 mL was prepared, next 1 mL oil out of the sample was drawn, and then was put into a small tube where it was diluted evenly with 1 mL C_2Cl_4. Finally, the oil used for experiment was ready[1], and the concentration of particle might be called 1 mL volume of magnetic particle (VMP). The following experimental steps are similar to those of DR ferrography. The same procedure was repeated three to five times.

Besides, the sample of 1 mL VMP and three other samples with different concentrations of particles, i. e. 0. 5, 0. 25 and 0. 1 mL VMP, were also experimented respectively. The results can be seen from Fig. 1, where ΔV is voltage difference, V is voltage reference. Fer Ut stands for ferrography unit. Mid is regular position where oil sample is put.

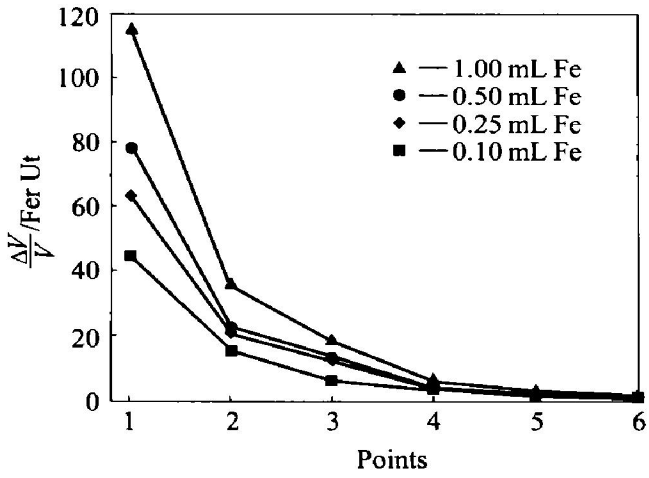

Fig. 1 Deposition curves of magnetic particle

According to the above procedures, the sub-magnetic particles of aluminum and copper were also tested. Four concentrations were used for the experiments. They were 1. 0, 0. 5, 0. 25 and 0. 1 mL volume of sub-magnetic particle (VSP), respectively. For each concentration, the measurement was repeated three times. Figs. 2 and 3 show the experimental readings. Compared with Fig. 1, the figures show almost the same shape. There is much difference of susceptibility between these particles. Therefore, it can be assumed that the sub-magnetic particles do not deposit randomly as believed before. There is a certain amount of chance that sub-magnetic particles deposit both at the entrance of tube and along the direction of fluid oil. At the entrance, the chance of particle's deposition is much larger, while along the direction ahead the chance is smaller. The distribution approximately conforms to the magnetic particles.

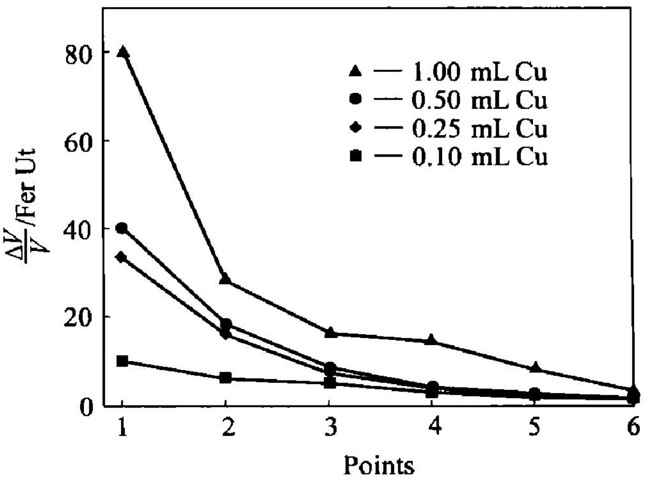

Fig. 2 Deposition curves of sub-magnetic particle

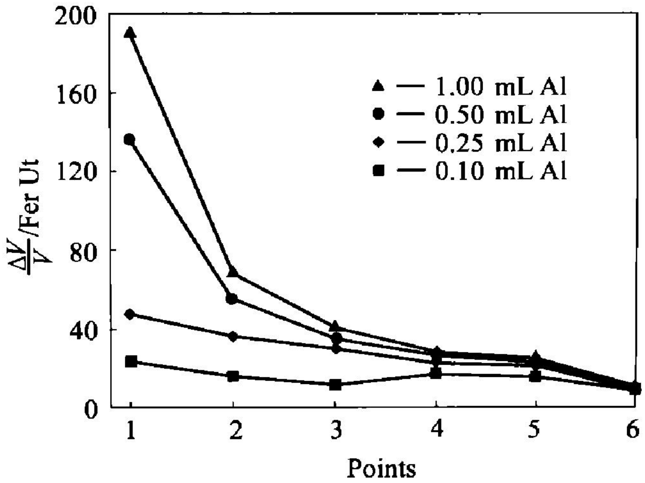

Fig. 3 Deposition curves of sub-magnetic particle

2.2 Experiments of blended particles

Apart from single particle experiments, multi-particles experiments were also done in this study. The main purpose is to observe the results for blended particles. The experimental conditions are the same as above. 0. 5 mL magnetic oil as base oil was used, and then different volumes of sub-magnetic oil of copper were added to form the blended oil samples. The added volume was 1. 0, 0. 5 and 0. 25 mL, respectively. Therefore three different concentrations of oil sample were prepared. Fig. 4 illustrates the experimental results. The results for oil samples of different concentrations of aluminum particles can be seen from Fig. 5. These figures show that the values of each point are much higher than those of single particles whether they are magnetic or sub-magnetic. However, the shape of the curves in Fig. 4 is similar to that in Figs. 1 - 3.

Oil samples of different concentrations of three particles were also studied. Different volumes of copper particles and aluminum particles were added. The experimental results are illustrated in Fig. 6. The

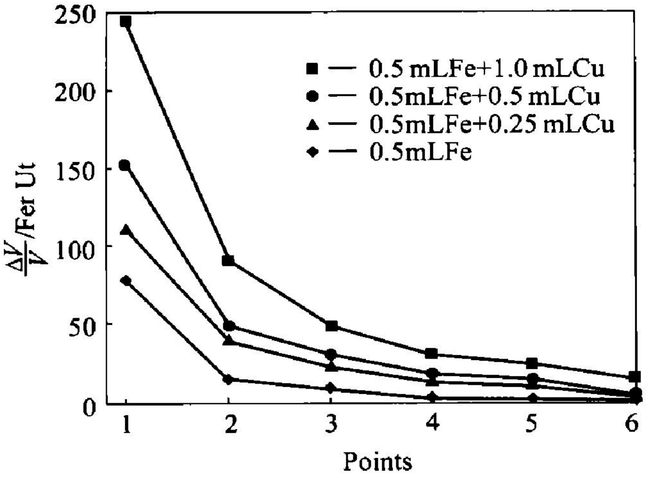

Fig. 4 Deposition curves of magnetic and sub-magnetic particle

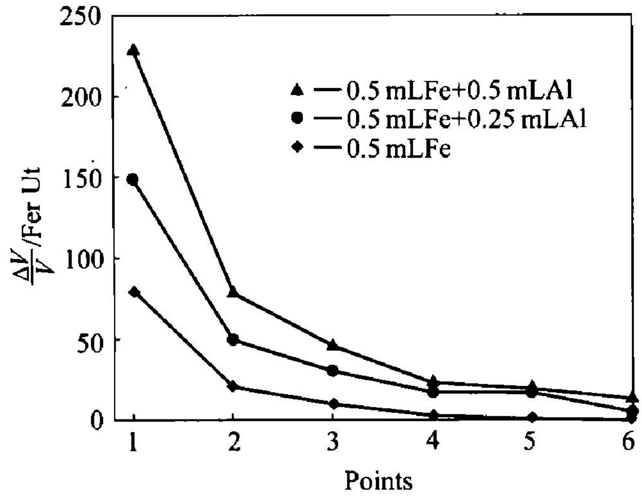

Fig. 5 Deposition curves of magnetic and sub-magnetic particle

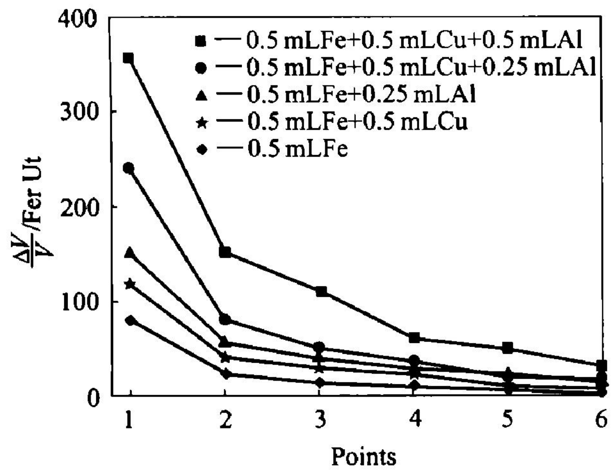

Fig. 6 Deposition curves of compound particle

shape of deposition curves is almost the same as the above figures. The figures show that the values of each point are much bigger than any other figures no matter whether they are single particles or multi-particles. That is to say, the chance of deposition for multi-particles oil is larger than that of single particles oil. In short, the same conclusion as above is drawn.

2.3 Further analysis of experiments

Since four additional monitoring points were added to MPMI, a wider scope of deposition can be detected. Therefore, more information of particles is obtained. To the DR ferrography with two monitoring points, the total quantity of wear is equal to the sum of D_l and D_s. D_l is the value of the first monitoring point and D_s is the second[9, 10]. Q_s is used to stand for this sum. Compared with Q_s, Q_a is used to stand for the total quantity of wear in MPMI. In fact, Q_a is the sum of readings of all the six points. Obviously, Q_a is greater than Q_s. For sub-magnetic particles and magnetic particles, the values of Q_s divided by Q_a are listed in Table 1. In Table 1, Q_n stands for the sum of the last three monitoring points, which may be defined as sub-magnetic particles' total quantity of wear. Experimental data of magnetic particles mixed with sub-magnetic particles in different concentrations are listed in Table 2.

Table1 Experimental data of magnetic particles and sub-magnetic particles(volumn fraction, %)

Samples	Fe		Al	
	Q_n/Q_a	Q_s/Q_a	Q_s/Q_a	Q_n/Q_a
0.25mL(mid)	85	6	59	25
0.5mL(mid)	88	5	72	16
1.0mL(mid)	87	5	76	12
0.25mL(hig)	81	11	59	23
0.5mL(hig)	86	6	67	20
1.0mL(hig)	87	6	76	12
Average(sum)	86	6.5	68	18

Table 2 Experimental data of magnetic particles mixed with sub-magnetic particles (volumn fraction, %)

Sample(mid)	Q_s/Q_a	Aver	Q_n/Q_a	Aver
0.25mlFe+ 0.25mlAl	78 83	80	13 10	11
0.25mlFe+ 0.25mlAl	73 74	74	14 14	14
0.5mlFe+ 0.5mlAl	75 77	76	15 12	13
Average(sum, above)	76			13
Sample(mid)	Q_s/Q_a	Aver	Q_n/Q_a	Aver
0.5mlFe+ 0.25ml Cu+ 0.25mlAl	77 77	77	13 12	13
0.5mlFe+ 0.5ml Cu+ 0.5mlAl	68 69	69	18 17	18
Average(sum) *	72			16

In the tables, mid and hig are the different positions where the oil samples are placed. The value of hig is one and a half larger than that of mid.

According to the tables, different concentrations of oil samples, particles and positions lead to different results. The values of Q_s/Q_a change as well. To the magnetic particles, the values of Q_s/Q_a vary between 81% and 88%, with an average of 86%. That is to say, the traditional total quantity of wear(Q_s) is only a part of the real total quantity of wear(Q_a), with an ratio of about 86%. To the sub-magnetic particles of Al, the values of Q_s/Q_a vary between 59% and 76%, with an average of 68%, and the values are smaller.

The experiments of the mixture of magnetic and sub-magnetic particles show the same result, as shown in Table 2. To the mixed oil samples of Fe and Al, the values of Q_s/Q_a vary between 73% and 83%, with an average of 76%. To the most complicated oil samples of Fe, Al and Cu, the values of Q_s/Q_a vary between 68% and 77%, with an average of 72%. To sum up, it is assumed that the difference between Q_s and Q_a will be enlarged as sub-magnetic particles increasing in the oil samples. In other words, the traditional total quantity of wear(Q_s) is incomplete. The values of Q_s can reflect only part of the practical situations. All things considered, the redefined total quantity of wear(Q_a) is more acceptable.

5 CONCLUSIONS

1) A new particle monitoring instrument MPMI was developed, which is helpful to monitor the magnetic particles as well as the sub-magnetic particles.

2) Both sub-magnetic particles(copper and aluminum) and magnetic particles do not deposit randomly in the precipitator tube. Their deposition curves are approximately similar. That is they are hyperbolic curves, though there is a different value of each point among the curves. The chance of particles deposition is increased for the oils with different kinds of particles.

3) On the base of these experiments, a new index used for wear was redefined, i. e. the total quantity of wear(Q_a) .

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(Edited by LI XIANG-qun)