Security Sensor System Based on Large Barkhausen Jump of Amorphous Magnetostrictive Metal Wires

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ABSTRACT

This paper presents and discusses preliminary laboratory results for fabrication and testing of a security sensor system for use in article surveillance in such places as libraries, CD rental shops, and supermarkets, as a crime preventive measure. The system employs the large Barkhausen jump (LBJ) inherent in the amorphous magnetostrictive metal wires. The system takes advantage of the superior sensor characteristics of magnetostrictive metal wires.

1.0 INTRODUCTION

Crime has always been a source of concern for large sections of the society, but at no time has this concern been deeply entrenched and fervently expressed as it is today. To counter such crime, there is need to develop more technologically sophisticated ways of outwitting the criminal and protecting property. In view of the above security sensors have become even more important today.

Sensors based on magnetic materials (and especially amorphous magnetic materials) have, on the other hand, attracted attention in recent years owing to the various desirable characteristics they possess over other sensor materials (Mohri 1984). For instance, such sensors have high signal to noise ratio, better temperature stability, compared to for instance semiconductor sensors, higher reliability and higher operating frequency range, among others.

Studies on the effect of stress on various parameters of magnetostrictive amorphous ferromagnetic wires have been conducted to date (Nderu *et al.* 1995, 1997 and 1999) with the aim of understanding their fundamental magnetic behaviour under stress, as well as seeking possible applications based on such behaviour. One of the magnetic features of wires that has previously been discussed is the phenomenon referred to as "large Barkhausen jump" (LBJ) (Nderu *et al.* 1996). This paper discusses one possible application of the LBJ phenomenon in article surveillance systems in libraries, supermarkets, and CD rental shops.

The system was fabricated and tested in the laboratory. Functional tests in the laboratory established that the system responds when an item is being taken out illegally. An advantage of the present system is that the magnitude of the voltage generated in the sensing coil is large. The system is thus expected to be less prone to ambient noise. A disadvantage of the security tag using amorphous wire, however, is that the tag is rather long (about 7 cm for a 125 μm diameter wire employed in this work). The trade off is that the threshold wire length increases with the wire diameter, while if one tries to decrease the wire diameter so as to decrease the threshold length, the amplitude of the pulses generated by the LBJ decreases greatly.

2.0 LARGE BARKHAUSEN JUMP (LBJ)

The magnetization process of a ferromagnetic material does not proceed smoothly as the value of the magnetic field is increased from zero to saturating field. Thus, if the hysteresis (M-H) loop of a ferromagnetic material is taken on a sensitive scale it is observed that it is not a smooth loop, but consists of numerous small jumps of the magnetization as the field is increased. However, when the loop is taken under normal scale the jumps are not evident and the hysteresis loop looks smooth. The "jumping" phenomenon of the magnetization was first made clear by Barkhausen, hence Barkhausen jump (discontinuity) (Chikazumi 1964). The jumps are of different magnitudes depending on the state of the material and can be enhanced or reduced by various treatments of the material such as heat treatment, and application of stress (in the case of magnetostrictive materials). However, it is not normally possible to enhance the jumps permanently since they return to normal size as soon as the enhancing parameter is withdrawn.

The uniqueness of the jump in the amorphous magnetostrictive ferromagnetic wires is that it is especially pronounced. In fact, in the $Fe_{77.5}Si_{7.5}B_{15}$ amorphous wire of about 120 μm diameter and 7 cm long, the jump is about 50 % of the saturation magnetization, hence large Barkhausen jump, and occurs at a single value of magnetic field, called switching field (H*). More importantly, the large Barkhausen jump in the amorphous wire is permanent and occurs even in the as-cast wire with no additional treatments. Furthermore, the LBJ is observed over a wide range of frequencies, from 0.01 Hz - 10 KHz (Mohri *et. al.* 1985).

The unique reversal (jump) of magnetization of the amorphous wire can be best illustrated by referring to the set of the hysteresis loops seen in Fig. 1, which shows the change in the shape of the M-H loop as the amplitude of the field is varied. Loops of $Fe_{77.5}Si_{7.5}B_{15}$ wire with positive saturation magnetostriction ($\lambda_s = 34 \times 10^{-6}$) are shown in (a); $(Fe_6Co_{94})_{72.5}Si_{12.5}B_{15}$ wire with very low negative saturation magnetostriction ($\lambda_s = -0.1 \times 10^{-6}$) in (b); and negative saturation magnetostriction ($\lambda_s = -2.3 \times 10^{-6}$) $Co_{72.5}Si_{12.5}B_{15}$ wire in (c). It is important to note that the main differences in the loops appear due to the difference in the saturation magnetostriction constant, λ_s, (a function of chemical composition). The effect of stress on a ferromagnetic material is governed by both the magnitude and sign of saturation magnetostriction constant (Chikazumi 1964). With the drive field very low as with the first loop in the set, there is no flux change for the magnetostrictive wires (a) and (c), whereas the wire in (b) displays the normal minor loop expected of square loop magnetic materials.

As the drive field is increased, wires (a) and (c) reach a sharp threshold, above which their magnetization reverses (jumps) very abruptly. This sudden jump of magnetization at H* is the large Barkhausen jump. The threshold H* is typically reproducible to ±3m Oe. Reasonable increases in the field do not produce more flux change. However, if the field is increased to a very high value as shown by the last loop, it becomes clear that the low field remanence is only a fraction of the saturation. The non-magnetostrictive wire (b) saturates at a reasonably low field.

Due to the LBJ, amorphous magnetostrictive metal wires generate very sharp and stable voltage pulses in ac fields of more than 0.08 Oe (6.4 A/m) at frequencies from 0.01Hz-10KHz (Mohri *et. al.* 1985). These very stable pulses are seen at the pick-up coil or between both ends of the wire due to the large Barkhausen jump and Matteucci effect, respectively. Matteucci effect is a phenomenon whereby if a cylindrical magnetostrictive ferromagnetic specimen is twisted and in this state an ac magnetic field is applied along the axial direction of the specimen, a voltage pulse is detected across the specimen. It is important to note here that though both Matteucci as well as LBJ pulses are present in the amorphous wire, the security sensor in article surveillance system can only utilize the pulses from the LBJ since the sensor (amorphous wire) has to be embedded in the article to be monitored.

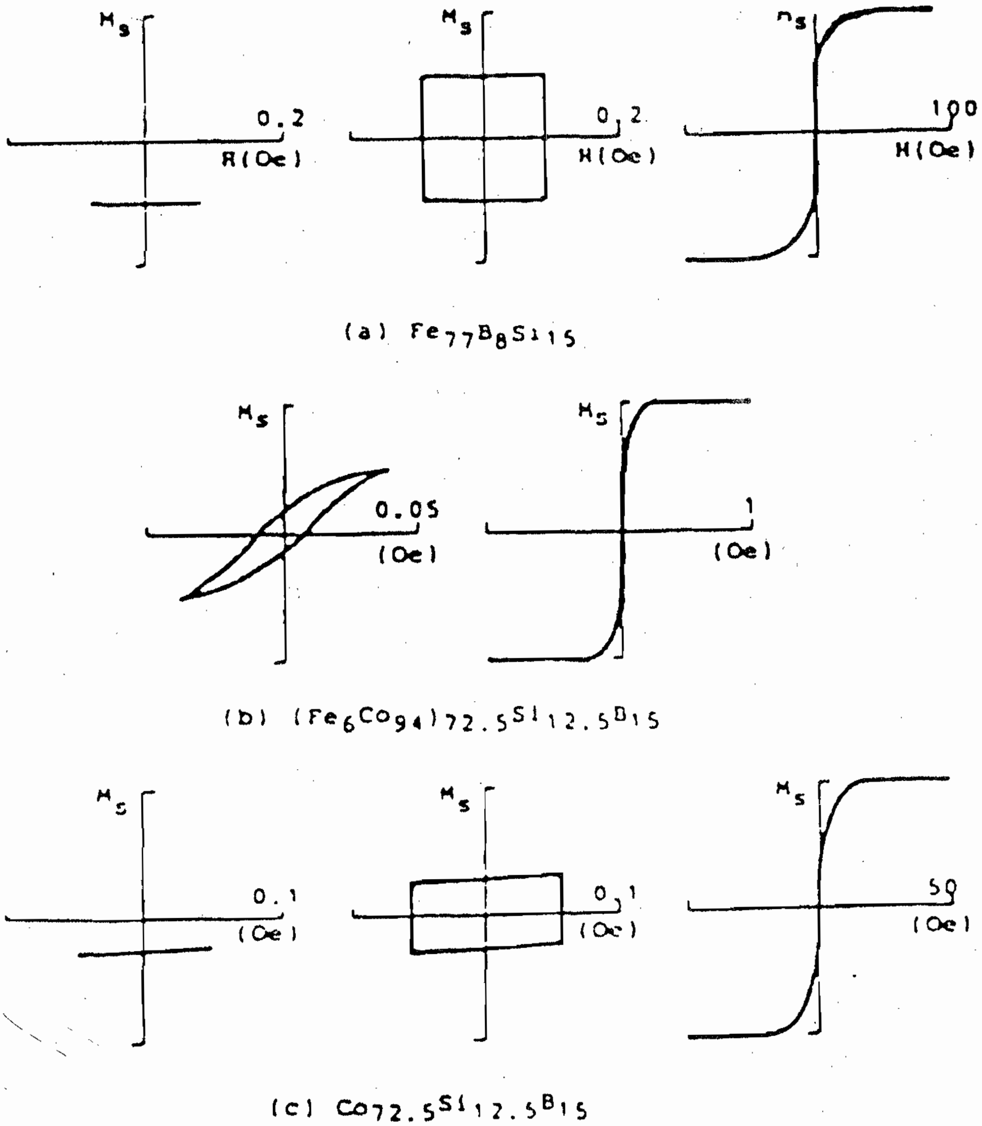

Figure 1. Change in the shape of the M-H loop as the amplitude of magnetic field is varied

Pulses from LBJ in $(Fe_{50}Co_{50})_{78}Si_7B_{15}$ wires and also two M-H loops, with the same origin and vertical scale, are shown in Fig. 2. The loops were taken using an X-Y recorder. The square loop (low field loop) is drawn on a horizontal scale of 0.4 Oe. This loop is included to make evident the LBJ phenomenon and show that it occurs at a single field. The high field loop is drawn on a horizontal scale of 100 Oe. This loop serves to show that after the LBJ the saturation magnetization (Ms) of the material has not yet been attained.

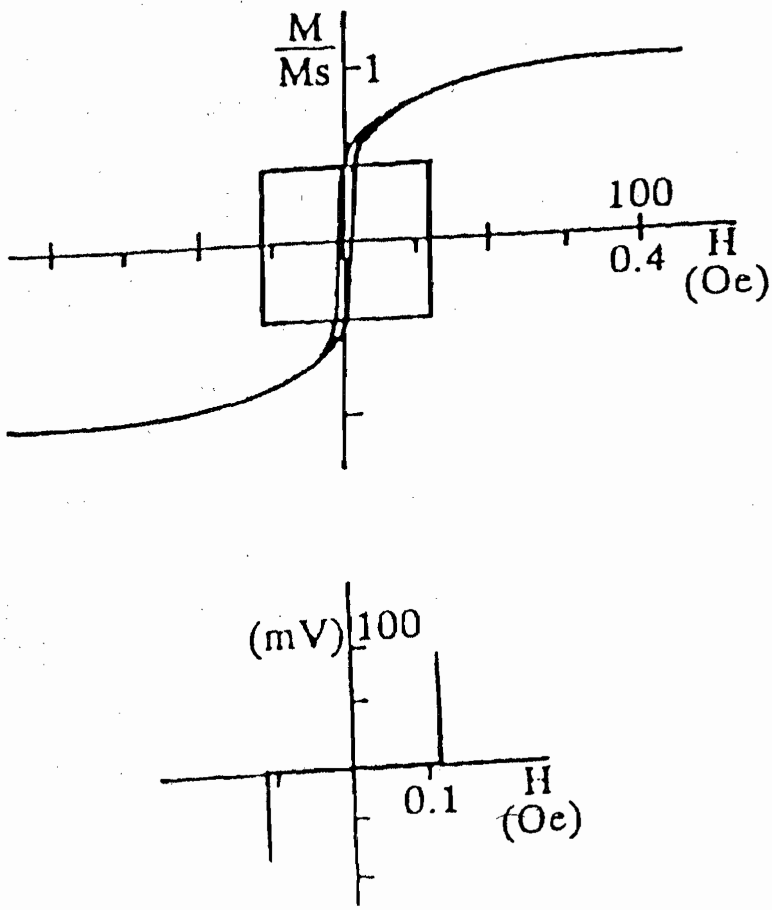

Figure 2. Pulses from LBJ in $(Fe_{50}Co_{50})_{78}Si_7B_{15}$ wire of diameter 160 μm

Thus, it is still possible to magnetize the material to Ms by increasing the field further. Superimposing the two loops makes it easier to see the fraction of Ms covered by the LBJ. Comparison of the low and high field loops in Fig. 2 show that, in this wire, the LBJ covers about 50 percent of Ms. The voltage pulses shown, coincide with the LBJ as they are induced by the sudden flux change during the LBJ, in a sensing coil wound around the amorphous wire.

3.0 ARTICLE SURVEILLANCE SYSTEM

3.1 Security Sensor Tags

Security sensor tags are employed in article surveillance systems and depend upon the unique flux reversal character of the tag. When this scheme was first used, Perm-alloy was employed. This is because Perm-alloy is very soft magnetically. It has a very high permeability meaning that its loop resembles that of an LBJ. However, the loop of Perm-alloy does not contain a single large jump of magnetization, but consists of several relatively large jumps close to each other, which when looked at normal scale would seem like a large jump. The jumps are, however relatively large and present in the material with no permanent enhancement. Owing to this, Perm-alloy was the best material for use in surveillance systems during its time. In the recent past, however, amorphous wires have been shown to display large Barkhausen jump, which is seldom seen in other systems and never without a large set field to drive out the reverse domains after a reversal (Mohri *et al.* 1985). Owing to this, the as-cast wire is natural as a security sensor tag, and this is a good application for the wire since it is cheap enough to be disposable.

In a security sensor system, the subject usually walks between two posts or pillars. These pillars supply a weak interrogation field and also contain the detector unit to sense that there is a magnetic material in the interrogation field. Perm-alloy, as well as other magnetic materials (such as magnetic pastes) will give a weak low signal when far away that slowly changes to a sharp signal when the tag is in the stronger part of the field. The reason for this, as mentioned above, is because its magnetization process does not consist of a single large jump at a definite value of field, but of numerous relatively large jumps close to each other. The situation of separate jumps of flux is undesirable because when the jumps are spread out the signal generated in the sensing coil is low and the sensor is then more prone to ambient noise. Amorphous wire, on the contrary, does not respond until the field reaches the switching field, H*. At that time and for all higher fields, the wire responds in a sudden manner, giving the same reversal signature. The only real problem with the amorphous wire as a security tag seems to be that the tag must be rather long since the minimum length of wire required to support the LBJ phenomenon increases with the wire diameter. This length is at least 7 cm for a 125 μm-diameter $Fe_{77.5}Si_{7.5}B_{15}$ wire (Nderu *et al.* 1997). The trade off is, therefore, that the threshold wire length increases with the wire diameter, while if one tries to decrease the wire diameter so as to decrease the threshold length, the amplitude of the pulses generated by the LBJ decreases greatly.

3.2 Characteristics of Article Surveillance Systems

An article surveillance system is required to have the salient features listed below:

i) It should produce an alarm when the article is being taken out illegally.

ii) It should produce no alarm when the article is borrowed.

iii) It should allow free movement to persons carrying personal items (not really a problem since such items do not contain any magnetic material).

iv) It should have a mechanism to reset the sensor system, ready for the next action, after the alarm signal has been attended to.

The above features are expected to be met by the system employing the amorphous wire and also in the current system.

3.3 LBJ Article Surveillance System

Fig. 3 outlines the complete article surveillance system. The sensor (amorphous wire) is embedded in the item being monitored. When moving out the subject walks between the two pillars shown. These pillars supply an interrogation field of magnitude large enough to initiate the large Barkhausen jump. They also contain a detector unit to sense that there is a magnetic material in the interrogation field. In the case of the amorphous wire, either a longitudinal or circumferential field can initiate the LBJ. Thus, the angle at which one is holding the wire (monitored item) relative to the interrogation field will not be an impediment.

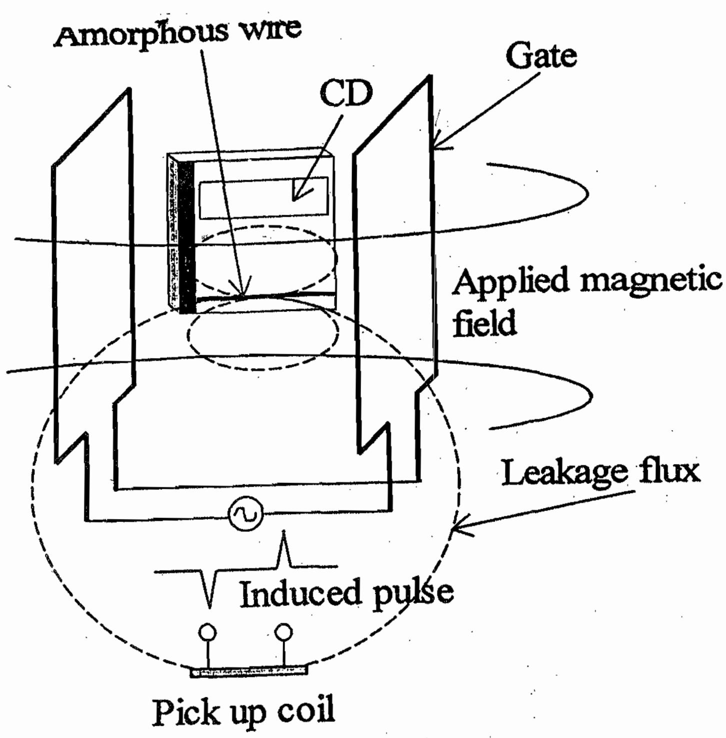

Figure 3. Outline of the complete article surveillance system used in our laboratory tests (similar set up would be used in actual application)

3.4 Operation of LBJ Sensor

The operational characteristic of the LBJ sensor is shown in Fig. 4 which is an enlargement of the square loop shown in Fig. 1 (a). This figure illustrates how the features necessary for a security sensor system are obtained from the LBJ of the amorphous wire. The reference magnetic status of the wire is always maintained at point A of the M-H loop. This is the "Storage State" of the items, that is, the point to which the magnetization state of the wire must be restored, ready for the next action, when a borrowed item is returned.

If a person tries to take out an item illegally, he will encounter the interrogation field at the gate. The polarity of the interrogation field is such that it will drive the magnetization of the wire towards the left from point A. Furthermore, the magnitude of the interrogation field is maintained at a value large enough to drive the magnetization beyond point F. Owing to this the magnetization will switch to the negative remanence, point E. This sudden change in the magnetization causes oscillation in the interrogation field. As a result of the oscillation, a voltage is induced in the sensing coil hidden within the vicinity of the interrogation field. This voltage is amplified and used to drive an alarm. The alarm signal may also be used to simultaneously generate counter action such as not opening the gate or closing the gate. It is worth noting that if the gate field is reversed the design of the sensor system will be such as to set the reference at a point diametrically opposite point A, that is, point D.

In case proper borrowing procedures are followed the following will be done. A field of the same polarity as, and of slightly greater amplitude than the interrogation field will be applied at the counter to force the magnetization to switch from point F to point E. In this case, passing the item via the interrogation field will only magnetize the wire much further to the left from point E. This will not cause large Barkhausen jump and therefore no alarm signal will be generated. To reset the system, a field of polarity reverse to the interrogation field and of magnitude large enough to restore the magnetization to point A is applied to the wire at the borrowing counter. The analysis above shows that the salient features required for an article surveillance system are obtained from the LBJ characteristic of the amorphous wire.

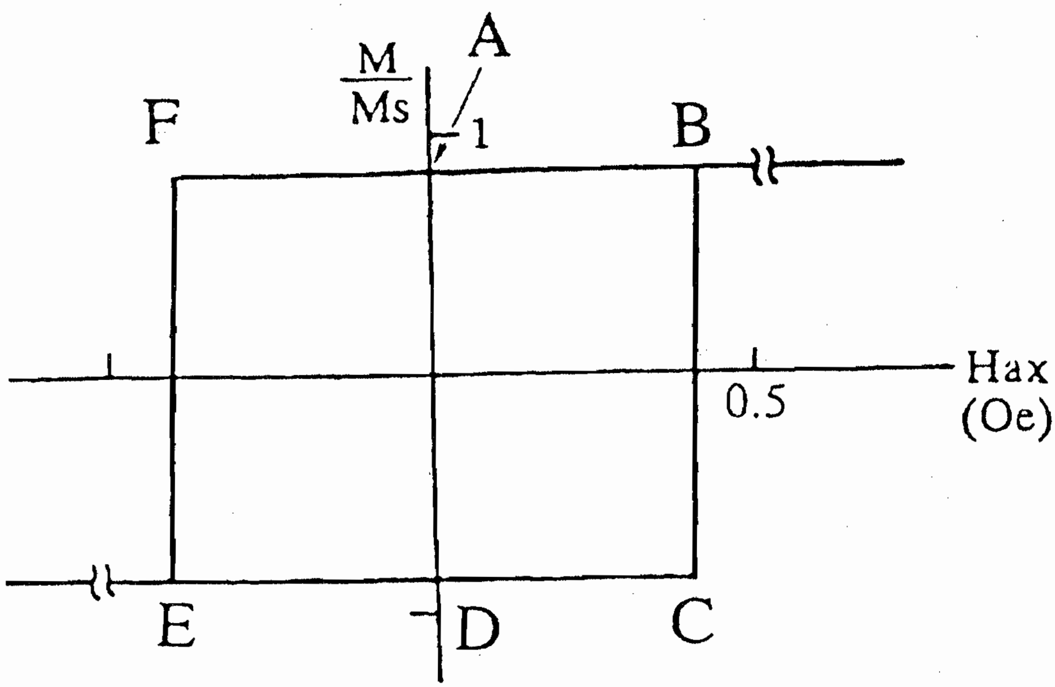

Figure 4. Illustration of how the features necessary for an article surveillance system are obtained from the intrinsic magnetic characteristics of the amorphous wire

In the present security sensor system it is worth noting that there exists a possibility of generating an alarm signal at the diametrically opposite rising edge (C-B) of the loop when approaching the interrogation field from outside the building, even when carrying a properly borrowed item. To avoid such an occurrence a separate entrance without interrogation field will normally be provided for those entering the building (CD shop). There is also a possibility that the sources of magnetic field available in ordinary equipment could accidentally cause the magnetization to be restored to the reference point A (Storage-State). However the main equipment that can generate a large enough field will normally not be found in places of intended application for the present system. At the same time the magnetic field normally decays as one moves away from the source. Thus, unless someone is conscious of the principle of operation of the security system and intentionally wants to defeat it, which should never be allowed to happen, one will normally not be near enough to the sources of the ambient electromagnetic field as to experience a high enough field to disrupt the operation of the system.

4.0 RESULTS AND DISCUSSION

Figure 5 shows the variation of the voltage waveform, with time, of the signal induced in the sensing coil hidden within the vicinity of the interrogation field, when somebody passes via the interrogation gate with a CD which is not borrowed. The voltage pulses were taken using a digital oscilloscope. Figure 5 (a) shows the pulses when the length of the amorphous wire embedded in the CD is 7.5 cm while in Fig. 5 (b) the length of the wire is 13 cm. The Figures show the amplitude of the pulses is virtually constant for the two wire lengths. This is because once the wire is long enough to support the LBJ, the phenomenon is thereafter independent of the wire length and very little change is expected in the pulses. However, as mentioned earlier, there is a threshold wire length below which the LBJ is suppressed due to the demagnetization field, which increases as the length of the specimen is reduced or diameter is increased. In the case of the wire used in our experiment the threshold length is about 7 cm (Nderu *et al.* 1996). This is the reason why we used a minimum length of 7.5 cm. The voltage pulses shown in Fig. 5 are the ones amplified and used to trigger an alert system. This work has therefore established that when one has a CD that is borrowed the pulses are not generated even if one passes via the interrogation gate.

(a)

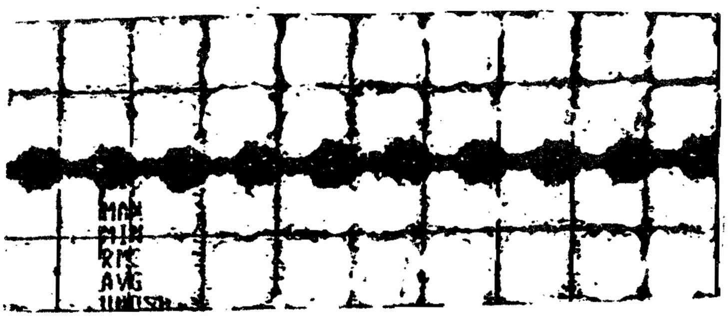

Figure 5. Variation of amplitude of voltage induced in the sensing coil with wire length, when someone passes via the interrogation gate with a CD that is not borrowed (a) for 7.5cm (b) for 13 cm long wire

5.0 CONCLUSION

Possible use of the LBJ inherent in amorphous magnetostrictive metal wires in article surveillance systems in libraries, supermarkets, and CD rental shops has been discussed. The system was fabricated and tested in the laboratory. The tests established that the system responds when an item is being taken out illegally.

A major advantage of the system employing LBJ of the amorphous wire is that it produces a voltage of larger magnitude compared to other systems such as those using ferromagnetic pastes and Perm-alloy. The system using the amorphous wire is thus expected to be less prone to ambient noise. One disadvantage of the security tag using amorphous wire, however, is that the tag is rather long since the minimum length of wire required to support the LBJ phenomenon increases with the wire diameter.

6.0 REFERENCES

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