

Investigation of the significance of the ‘body effect’ on sensitivity to metallic objects in a walk-through metal detector

L A Marsh^{1,4}, J Makkonen², J Vihonen², A Visa², A Järvi³,
D W Armitage¹ and A J Peyton¹

¹School of Electrical and Electronic Engineering, The University of Manchester, Manchester, M13 9PL, UK

²Tampere University of Technology, Department of Signal Processing, Korkeakoulunkatu 10, P.O. Box 553, FIN-33110, Tampere, Finland

³Rapiscan Systems Oy, Klovinpellontie 3, Tornio 2, FIN-02180 Espoo, Finland

E-mail: liam.marsh@manchester.ac.uk

Abstract. An investigation has been carried out to determine the extent to which a walk-through metal detection system is affected by the capacitive and inductive coupling between candidates’ bodies and the coil array – known as the ‘body effect’. In this experiment both small and large items are investigated to determine ratio of the signal contribution from the candidate compared to the object, and a comparison is made between the response of a small object both with and without the candidate. Also an experiment is presented to demonstrate the inductive / capacitive nature of this signal.

1. Introduction

Walk-through metal detectors (WTMDs) are widely used for personnel screening in security and checkpoint applications. The sensitivity of these detectors is limited by either interference, electronic noise in the receiver circuitry or by spurious inductive or capacitive coupling associated with the presence of the candidate, often known as the *body effect*. A similar limitation is encountered with other metal detection systems such as the *product effect* with on-line conveyor type metal detectors and the *ground effect* with metal detectors for detection of buried objects. This paper investigates the significance of the body effect signal compared to that of metallic targets. There has been little research into this area despite the potential sensitivity limit it presents. It is expected that by better understanding the body effect it should be possible to overcome this restriction.

In this paper a walkthrough metal detector (WTMD) capable of calculating the magnetic polarisability tensor of metallic objects, $\overleftrightarrow{\mathbf{M}}$, is used as a measurement system. The operation of this system is reported elsewhere [1]. Previous studies [2] have shown that the inductive signal from metallic objects can be related to the magnetic field via the magnetic polarisability tensor, $\overleftrightarrow{\mathbf{M}}$, which is represented as a complex, symmetric 3×3 matrix.

⁴ To whom any correspondence should be addressed

System measurements, λ , are related to the magnetic polarisability tensor and the incident magnetic field vectors as shown in equation 1.

$$\lambda = \overleftrightarrow{\mathbf{M}} \overrightarrow{\mathbf{H}}_{tx} \bullet \overrightarrow{\mathbf{H}}_{rx} \quad (1)$$

In this expression the vectors $\overrightarrow{\mathbf{H}}_{tx}$ and $\overrightarrow{\mathbf{H}}_{rx}$ correspond to the values of H-field for the transmit and receive coils respectively. The system inverts the tensor from the computed magnetic field data and measurements. However, this expression does not contain any terms which take into account the effect of the capacitive signal. Consequently any signals of capacitive nature cause errors in the data fitting in the inversion algorithm. In order to improve the data fit, and consequently to perform more accurate tensor inversion it is necessary to account for the capacitive input to the system prior to performing the inversion.

2. Background

Like all electrically conductive objects the human body can store electric charge and display capacitive properties. This behaviour is exploited by devices such as touch-screens, however the build-up of static electricity can cause damage to sensitive electronic components and in some electrostatically sensitive processes the operators must also be earthed via a tethered conductor. Typically the human body has a capacitance in the region of 100 pF [3].

In a similar way as eddy currents flow around metallic targets, they are also able to flow around the human body. This leads to the possibility of a distributed inductive response from the candidate as induced eddy currents circulate through conductive and dielectric body tissues. The electrical conductivity of human muscle is approximately $2.5 \times 10^{-1} \text{ Sm}^{-1}$ at 10 kHz [4]. Although this is considerably smaller than that of metallic targets e.g. aluminium at $3.58 \times 10^7 \text{ Sm}^{-1}$ [5] it is still measurable. As the human body is considerably larger than the pairs of transmit-receive coils throughout the detector the effect is distributed and consequently does not follow a response similar to the case of small metallic targets. Most biological tissues contain water, which is weakly diamagnetic, having a real magnetic susceptibility, χ , of about -9×10^{-6} [6] at room temperature. As a consequence of this it is known that the magnetic properties of water influence the magnetic properties of biological tissues.

An example of an inductive response from a metal object, in this case a model aluminium gun [7] as defined by the *US National Institute for Justice* (NIJ) is shown in figure 1; the x-axis has been normalised such that the object is defined as being in the centre of the detector at $t=0\text{s}$. It is possible to compare this signal with the coil geometry used to acquire it, which is shown in figure 3, note the symmetry of the object response, which results from the symmetrical design of the coil array. The coils shown in figure 3 display the fact that the transmit coil (shown in the solid line) contains a single crossover at the point $x=0\text{m}$ and the receive coil (shown with a dashed line) contains two crossover points at $x=\pm 0.18\text{m}$. These three crossover points are shown on figure 1 at the points $t=-0.23$, 0 and 0.2s .

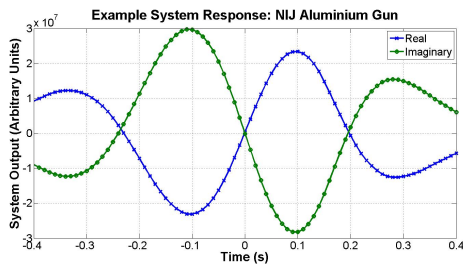


Figure 1. Example inductive signal

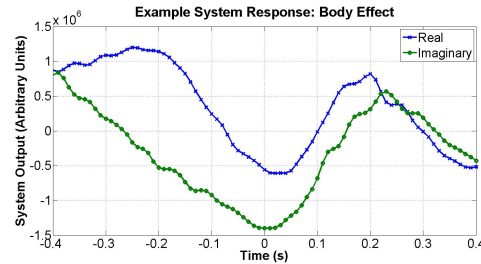


Figure 2. Example body effect signal

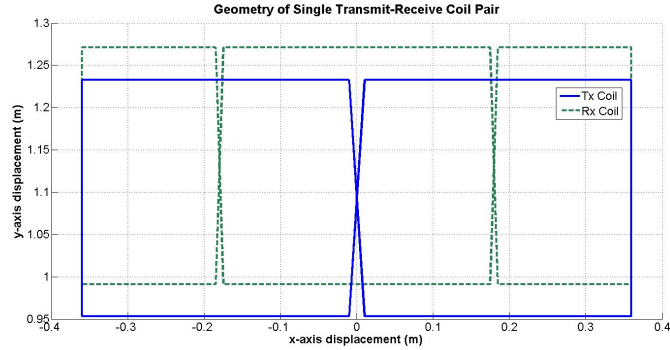


Figure 3. Example tx-rx coil pair

Unlike the high conductivity inductive signal shown in figure 1 a typical body effect signal does not follow a trend. An example of the signal produced by a ‘clean scan’ – i.e. from the passage of a candidate free from metallic objects is shown in figure 2. The data for this figure was obtained using the same coil pair used for the measurements shown in figure 1. Now however, there is no zero-crossing in the centre of the signal, no symmetry and the real and imaginary components are no longer proportional to each other (i.e. a straight line in the impedance plane), as is the case for the high conductivity inductive measurements.

3. Experimental Setup

Five candidates each made a total of 40 passes through the detector whilst wearing clothing which was free from metallic elements. Ten passes were recorded for when the candidate had no metallic items in their possession, and for the case when they carried steel and aluminium NIJ handguns and an NIJ aluminium knife [7]. On each occasion when the candidate was carrying an item it was placed at the midpoint of the detector with respect to the panel-to-panel displacement, a height of 1.1m with respect to the ground level and all points in the direction of transit through the detector (shown as the x, y and z-axes respectively on figure 4).

In order to determine the nature of the body effect, i.e. if it is predominantly capacitive or inductive, a second investigation has been conducted. This experiment consists of demonstrating the effect that grounding the candidate has on the portal, and the system response to saline of varying conductivity. In the first test a candidate entered the detector and remained inside the portal whilst stretching their right arm outside the sensitive region of the detector. After several seconds the candidate had a grounded wire touched against their right hand for several more seconds; this was then removed. Due to the fact that grounding the candidate is a capacitive action, a change in signal level is expected should the portal be sensitive to the capacitance of the body. The second test involved recording the signal response for a 10 L bucket of saline of varying conductivity from 13.83m Sm^{-1} to 11.18 Sm^{-1} .

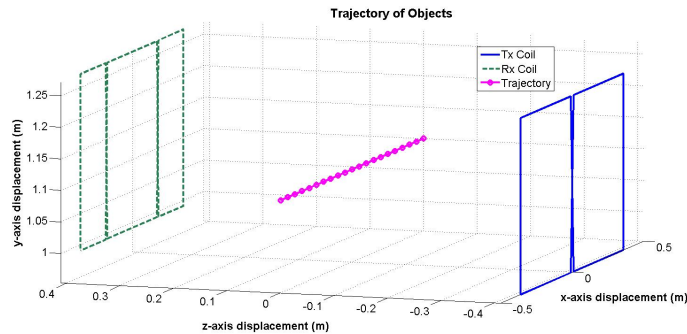


Figure 4. Approximate object trajectory

For each candidate a series of physical measurements were taken to allow for estimation of their body size. In total five parameters were measured – height, the peak width of shoulders, the peak chest size, the waist size and the height of the waist from the ground.

4. Results

The main results from this experiment are shown in figures 5 to 8. In each figure a total of ten walkthrough scans for each of the five candidates is shown. It is possible to see from figures 6 and 8 that the signal from the guns is so strong that it is difficult to see the effect of the body on the measurements. This is reflected in the fact that all of the scans are fully overlaid on one another. Figures 5 and 7 however show that the different candidates give distinguishable responses which are consistent across each of the candidate’s walkthroughs. Also included in figure 7 are the results for ten scans in the case when the object is not attached to a candidate. To achieve these measurements the object was attached to an insulating pole, and passed through the WTMD.

Although the measurements for the aluminium knife have a far smaller signal than that of the aluminium gun (approximately an order of magnitude difference) it is still possible to see that the two signals share a common phase bias; this is as a result of the response of the aluminium. However, in the case of the knife it is possible to see that this response is superimposed onto that of the body signal to produce the different candidate clusters shown. In the case of the candidate-free scan for the aluminium knife it is possible to see that the response (labelled ‘No Candidate’ on figure 7) is very linear. This figure clearly shows that the presence of a body along with the object can significantly obscure the target response.

Table 1 shows the Pearson correlation coefficient of the NIJ aluminium gun and aluminium knife for each candidate, averaged across all ten walk-through scans. It also shows the average for the candidate-free scan of the aluminium knife. The aluminium gun measurements show very strong correlation for all candidates with all values in excess of -0.99, thereby verifying that the body signal produced by the candidates has not significantly distorted the response. However, in the case of the aluminium knife the correlation is significantly worse for each candidate, ranging from -0.639 to -0.742. In contrast to these values the coefficient for the ‘no candidate’ case is in excess of -0.99. These results confirm that the system is capable of measuring a clear, linear response for small targets, however that they are adversely affected by the body effect.

In the case of the clean scans it is also possible to identify clustering of different candidates, however, as would be expected, this is not as obvious as with the aluminium knife. The results show that all five candidates show a distinctly repeatable response when walking through the detector, and with the exception of a single scan for ‘candidate 5’ the walk-through profiles do not significantly deviate from the main cluster for each candidate.

Table 1. Pearson correlation coefficient for aluminium targets.

Object	Candidate 1	Candidate 2	Candidate 3	Candidate 4	Candidate 5	No Candidate
Knife	-0.7420	-0.6329	-0.7017	-0.6536	-0.6388	-0.9994
Gun	-0.9974	-0.9989	-0.9967	-0.9996	-0.9993	<i>n/a</i>

Table 2 shows the recorded dimensions of each of the five candidates. The table shows that candidates 3, 4 and 5 are generally larger than candidates 1 and 2. However, the region of interest (1.1 m from the ground) corresponds approximately with waist-level for all candidates; the order of candidates from largest to smallest waist size is [4; 2; 3; 5; 1]. Analysis of the data in figure 5 shows that there is no clear correlation between waist size, or between the candidates’ physical size and the magnitude or phase of the response. This implies that the relationship between the candidate and the clean scan response is not directly based upon physical size of the body.

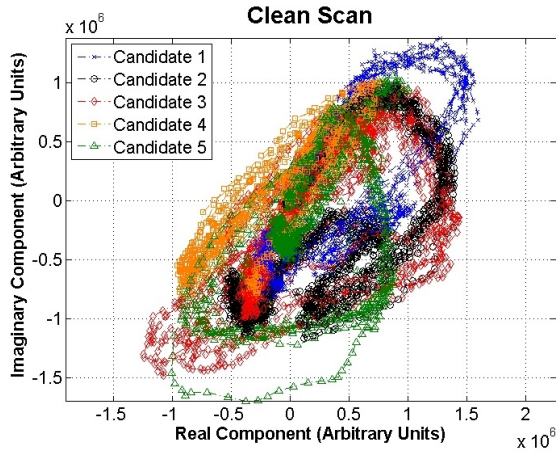


Figure 5. Results of clean scan

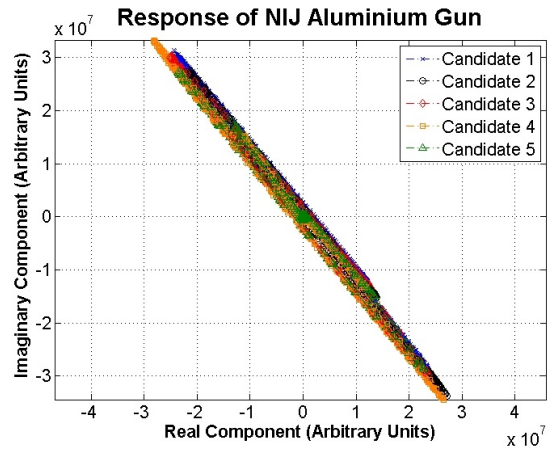


Figure 6. Results for NIJ aluminium gun

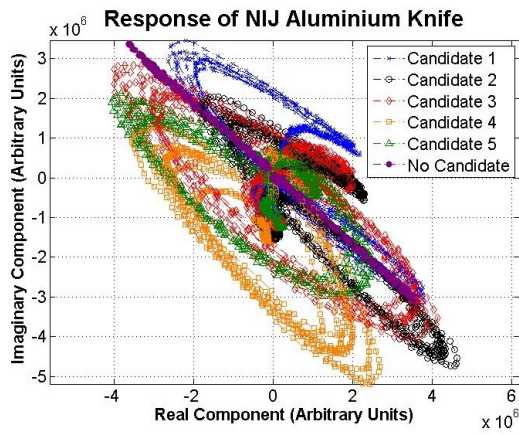


Figure 7. Results for NIJ aluminium knife

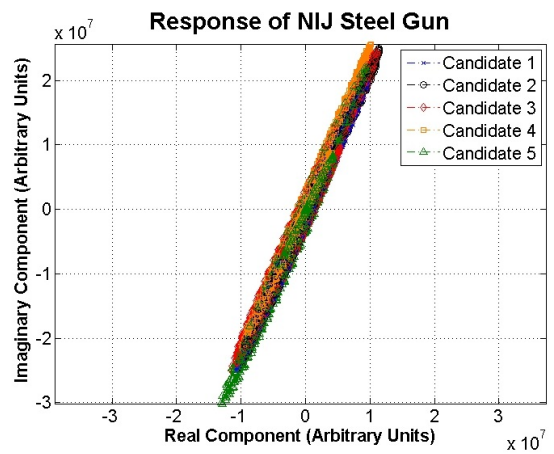


Figure 8. Results for NIJ steel gun

Table 2. Selected dimensions of candidates.

Dimension	Candidate 1	Candidate 2	Candidate 3	Candidate 4	Candidate 5
Height	1.79 m	1.74 m	1.87 m	1.86 m	1.85 m
Shoulders	1.15 m	1.04 m	1.34 m	1.23 m	1.17 m
Chest	0.96 m	0.99 m	1.09 m	1.10 m	1.02 m
Waist	0.86 m	1.06 m	1.02 m	1.10 m	0.94 m
Waist Height	0.98 m	0.95 m	1.07 m	1.05 m	1.00 m

4.1. Investigation of the Nature of the Body Response

Figure 9 shows the results of the tests for capacitive coupling. In figure 9(a) at sample reference $S=0$ the detector is empty. At approximately $S=400$ ‘candidate 1’ stepped into the detector space; the response jumps up at the point and settles down. At $S=750$ the candidate was grounded, and remained grounded until $S=2350$. The candidate then remained in the portal until $S=2850$. Each of these phases are clearly visible on the figure. The clear change that occurs when the candidate is grounded demonstrates that the body signal contains a significant capacitive component. In figure 9(b) the response is seen to vary almost entirely in the quadrature component as a function of conductivity. The offset of this linear response is also indicative of capacitive coupling between the coils and the saline.

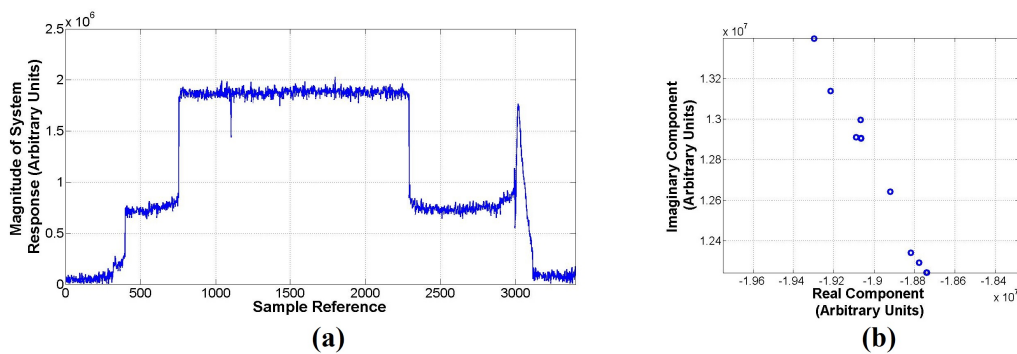


Figure 9. Tests for capacitive coupling between the candidate and the detector

5. Conclusions and Future Work

The results from this paper show that calibration for the body effect is not required for highly detectable objects such as the NIJ handguns; this is due to the fact that the inductive signal dominates in such cases as figures 6 and 8 show. However, there is a visible body signal in the case of both no metallic targets, and for small metallic targets as in figures 5 and 7 respectively. The experiments presented in this paper have demonstrated that a significant proportion of this body signal occurs as a result of capacitive coupling between the candidate and the coil array. The magnitude of this body effect response compared to that of small targets demonstrates a need for either calibration to account for the body signal, or screening to reduce it.

The results of this experiment demonstrate that the body effect appears to be distinct for each candidate. This is reflected in the fact that each of the five candidates produces a clustered response which is shown for all ten scans. This is an encouraging result as it demonstrates that the body effect is both measurable, and repeatable, which are two requirements for the development of a calibration routine.

The next step for this research, having identified the capacitive element of the body effect, is to establish a measurable, theoretical link which can be used to model it. This would then allow for the inclusion of the body effect into the forward model (equation 1) which would subsequently improve the quality of the measured data.

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