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EMF measurements and calculations on 6 arc and resistance welding processes with reference to the current draft of EMF Directive

electromagnetic fields & people

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Executive Summary

Six different welding processes were examined at sites in the UK. Maximum theoretical currents were derived for five of the processes, such that each would still meet the action values and health effect exposure limit values. These are as follows:

Process	Maximum current based on	
	Health effect exposure limit value	Action value
DC TIG welding	1.25 kA	506 A
AC TIG welding	9.3 kA	5.4 kA
Pulsed MIG welding	2.2 kA	550 A
50 Hz single-phase resistance welding	50 kA	13.6 kA
2 kHz MF DC resistance welding	5.3 kA	1.3 kA

All the machines were examined in controlled (non-manufacturing) situations so it is not possible to draw conclusions at this stage about the effects of different materials or processes on magnetic field exposures.

Introduction

Four arc welding processes and two resistive welding processes were investigated at sites in the UK in July and August 2011. The arc welding processes investigated were:

- DC TIG welding
- AC TIG welding
- Pulsed MIG welding
- Drawn arc (capacitive discharge) stud welding

The resistive welding processes investigated were:

- 50 Hz single phase welding
- 2 kHz mid-frequency DC welding

The aim of the investigations was to establish worst-case exposure results for equipment settings actually used in practice. All the sites visited were either manufacturing sector welding training facilities or the premises of welding equipment manufacturers.

Measurement equipment

A Narda STS ELT-400 magnetic field meter, calibrated at the UK's National Physical Laboratory, was used to measure exposure levels. This instrument has a frequency range of up to 400 kHz and a 10 cm diameter sensor that is representative of the size of the human hand. It is the instrument specified in several for testing in several European EMF product standards. For this project, this instrument was used in RMS, max hold mode, with a 1 Hz lower cut-off filter.

Magnetic field waveforms were captured using a Picoscope 3224 date capture and analysis system running on laptop computer. This is a fast analogue-to digital converter and dedicated software. It allows very rapid sampling (at data rates of many hundreds of kHz) and can capture data for several minutes at a time (or longer for lower sampling rates). It is a very useful system for capturing transients, pulses and non-periodic waveforms.

The Picoscope system was used either with a Bartington triaxis fluxgate magnetometer, or with the Narda STS ELT-400 magnetic field meter, which has an analogue data output port that can be connected directly the the Picoscope system.

Exposure limits

Levels of exposure of workers to magnetic fields from welding have been compared with the requirements of the EMF Directive.

For the purposes of this report, the magnetic field health effect exposure limit values in Table 2.1 of the EMF Directive are assumed to correspond to the action values of Table 2.3 for exposure of the torso. This is a very conservative assumption because it does not take into account non-uniformity of exposure (which will be significant) and it does not involve advanced and more-realistic computational modelling, which was beyond the timescale of this project.

However, it is very typical of electrical welding that the highest exposures are to the limbs and hands. The EMF Directive does not offer specific exposure limit values or action values for hands, but the derivation of one from the other should be quite different for hands than for the torso. Specifically, peripheral induced internal electric field from magnetic fields will be proportional to the mean radius of the conduction path, and hands have an effective radius four or more times lower than does the torso. On this basis, whilst there is no reason to compare exposures with a different exposure limit value for the hands than for the torso, it is logical to assume that the exposure level corresponding to this health effect exposure limit value is at least four times greater than the action value given in Table 2.3.

Arc welding

DC TIG Welding

The welder investigated was a Murex TransTig AC/DC 353F . This machine has three modes: AC, which is a switched square-wave current; DC reversed polarity mode and a pulsed DC mode.

The AC mode and DC pulse rates are frequency-agile, from 24 – 214 Hz, and in DC mode it is possible to vary the proportion of time that the current is negative or positive during the weld (the balance). Normal use at the site visited is at 50 Hz, and around 50% balance.

This machine uses an (approximately) 50 kHz current to initiate the arc. Because of this excitation, there was no apparent initial surge or pulse in magnetic field when the arc was initiated. The waveform of the magnetic field consisted of a series of 58 ms pulses with variable timing between them of 250-750 ms. Figure 1 shows the sharp rise in magnetic field corresponding to the initiation of one of these pulses.

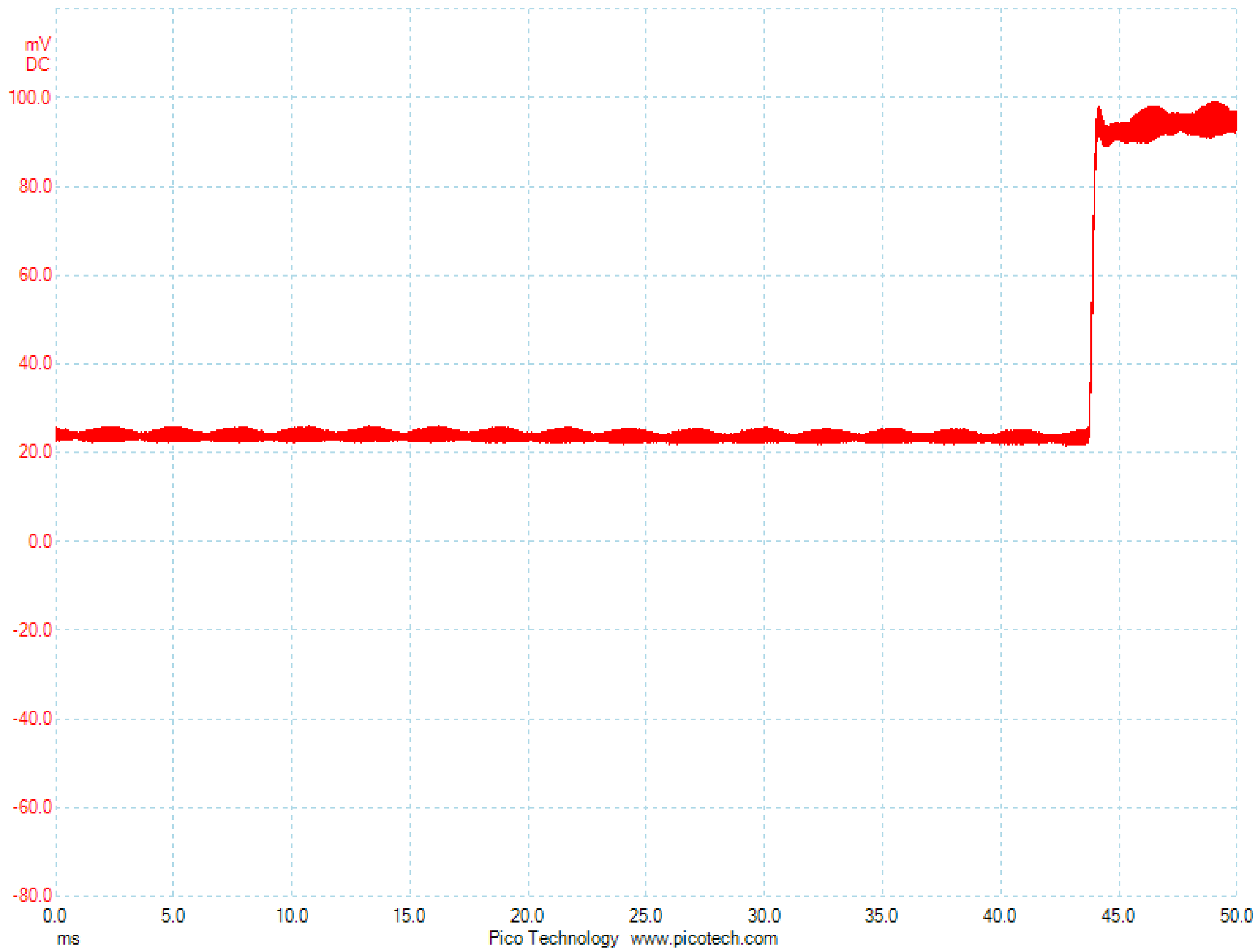

Figure 1 **Initiation of pulse in DC arc welding**

The pulse has a rise-time of approximately 300 μs and an amplitude of (depending on the measurement location) several tens of μT.

Figure 2 shows the end of the pulse, which has a rather slower decay than the rise shown in figure 1. On this basis it is the rise at the start of the pulse which is most significant in terms of human exposure.

Figure 3 shows the rise of the pulse in more detail, with an expanded timescale. The 58 kHz excitation can be seen clearly, but this makes up only around 10-15% of the amplitude of the pulse.

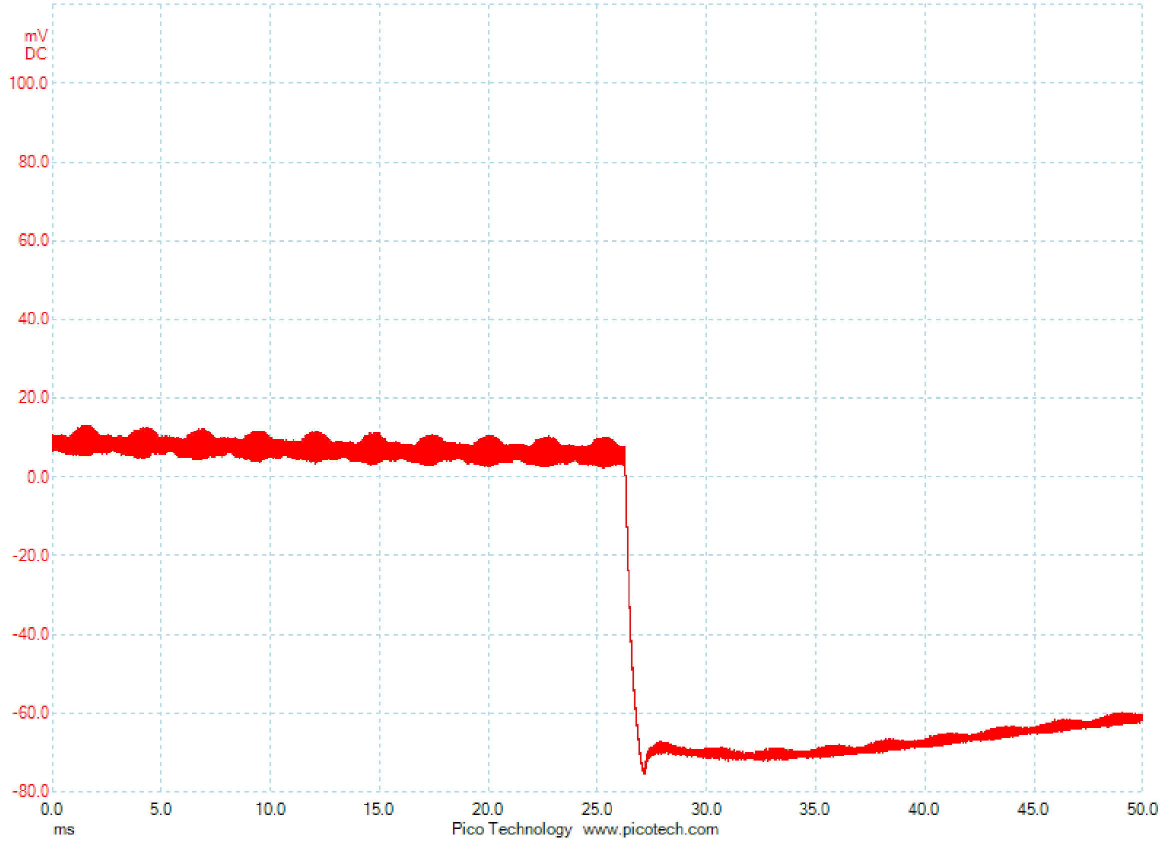

Figure 2 Decay of DC arc welding pulse

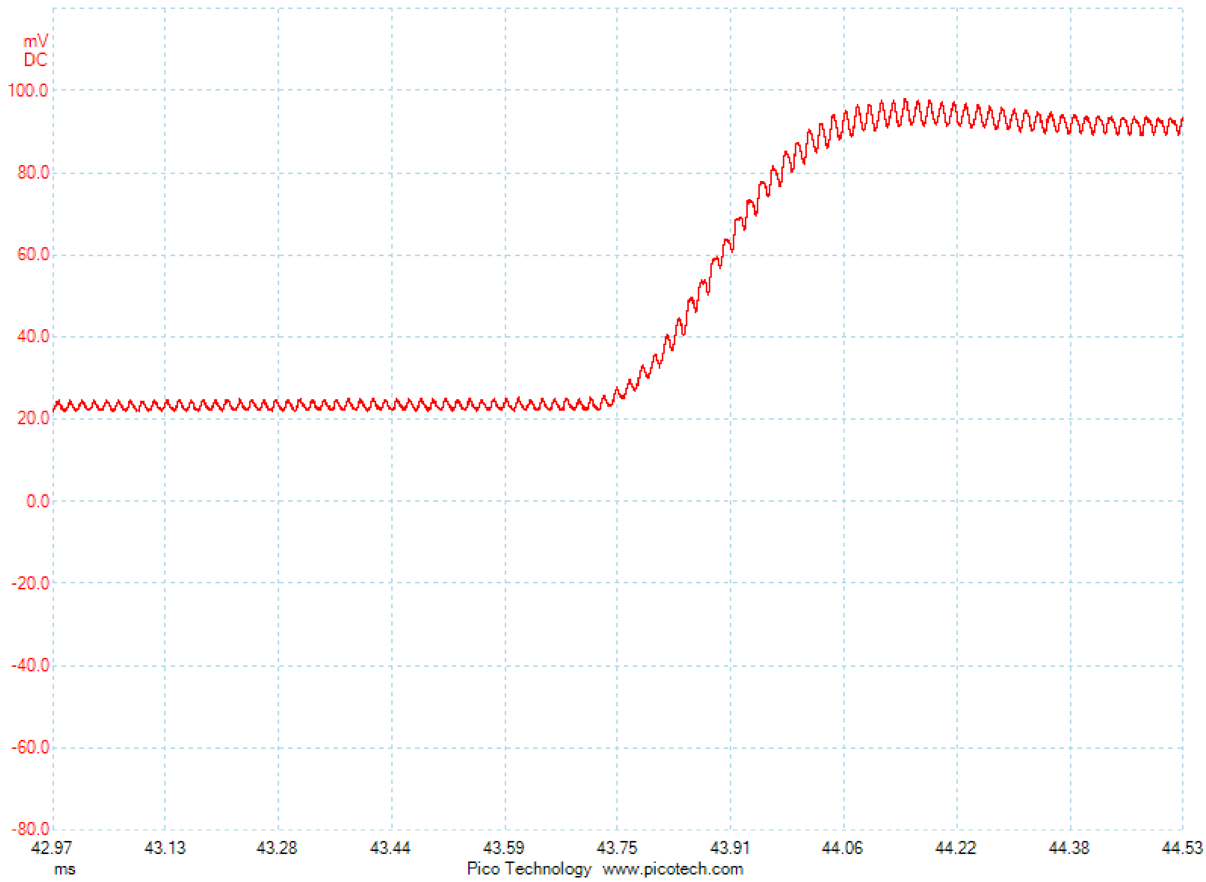

Figure 3 58 kHz excitation in DC arc welding pulse

This waveform is very difficult to analyse because it is not strictly periodic. The approach we have taken is to consider the principle component of exposure as being associated with the 300 µs rise time at the start of each pulse and to treat this as having an effective frequency of 3.3 kHz. For this frequency, the action value of the EMF directive is 222 µT.

The welder has a gun-type applicator with the arc striking perhaps 5 cm from the operator's right hand, the left hand being used to guide the work piece. Depending on the operator's stance, the torso would be approximately 30 cm from the arc and the head 45-50 cm from the arc.

The welder was operated on a test piece at a current setting of 114 A, and hand exposures were up to 50 µT, torso and head exposures between 10 and 20 µT. It can be shown (based on considerations of conduction path radius) that hands can exceed the action value by a factor of approximately 4 without the health limit values being exceed so for this machine the limiting exposure constraint would be the 20 µT torso exposure level. This is more than 10 times below the action value, so for this welder it would be possible to use a current of 1.25 kA before the action value or exposure limit were exceeded at the torso. If the action value at the hand posiiion were to be respected then the current could be increased by factor of 4.44 (222 µT/50 µT) to 506 A.

AC TIG welding

The same Murex TransTig AC/DC 353F machine was used to investigate AC arc welding. The operator position was similar to the DC welding situation.

Figure 4 shows the waveform of the magnetic field from this machine (again there was no apparent transient or irregularity as the arc was struck, presumably because of the 58 kHz excitation).

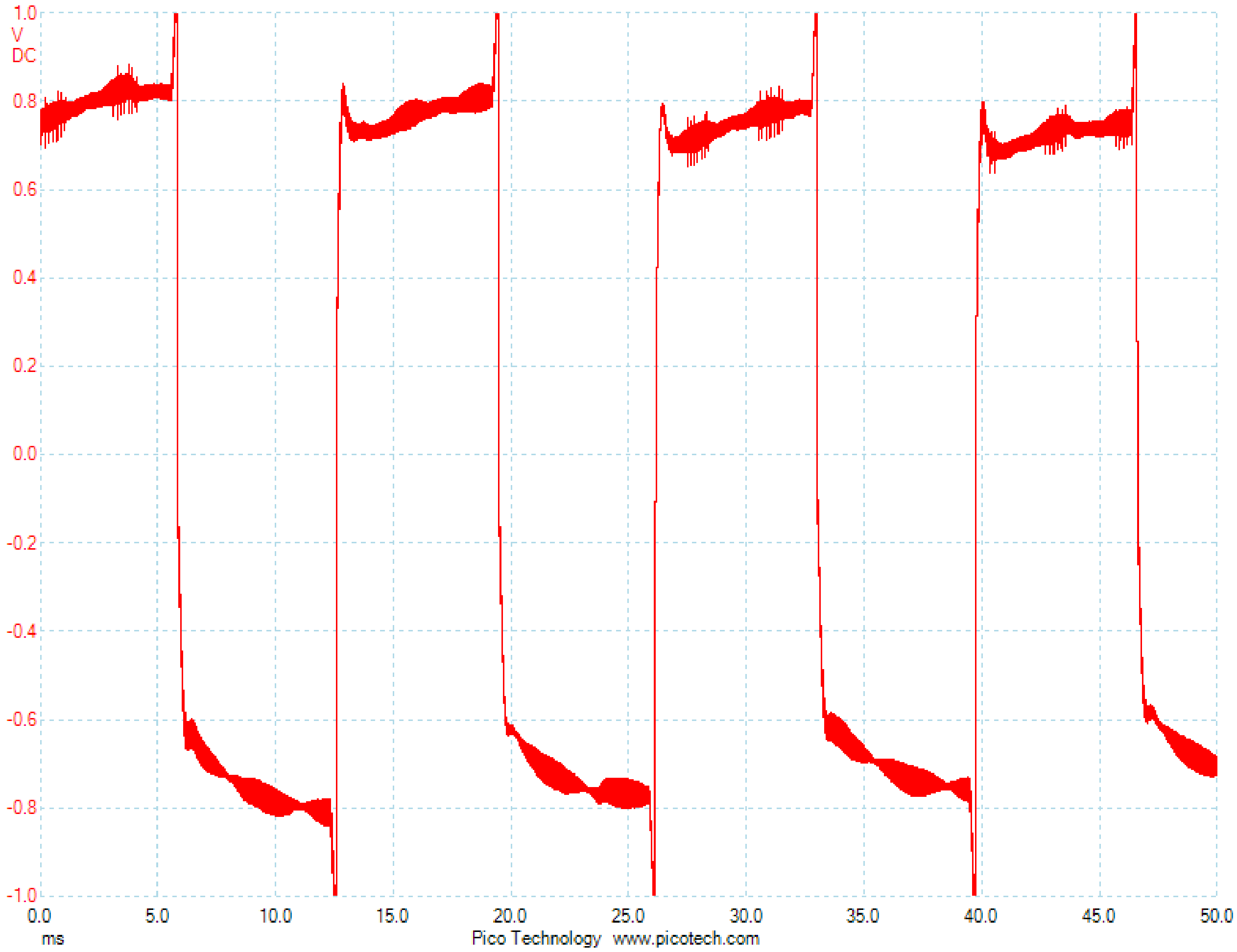

Figure 4 AC arc welding waveform

This waveform is much simpler to analyse, because it is periodic. The period is 13.55 ms, giving a fundamental frequency of 74 Hz. The 58 kHz component here is about 2% of the peak magnetic field so can be neglected in terms of its contributions to human exposure. Figure 5 shows the 58 kHz signal in more detail, using an expanded time axis.

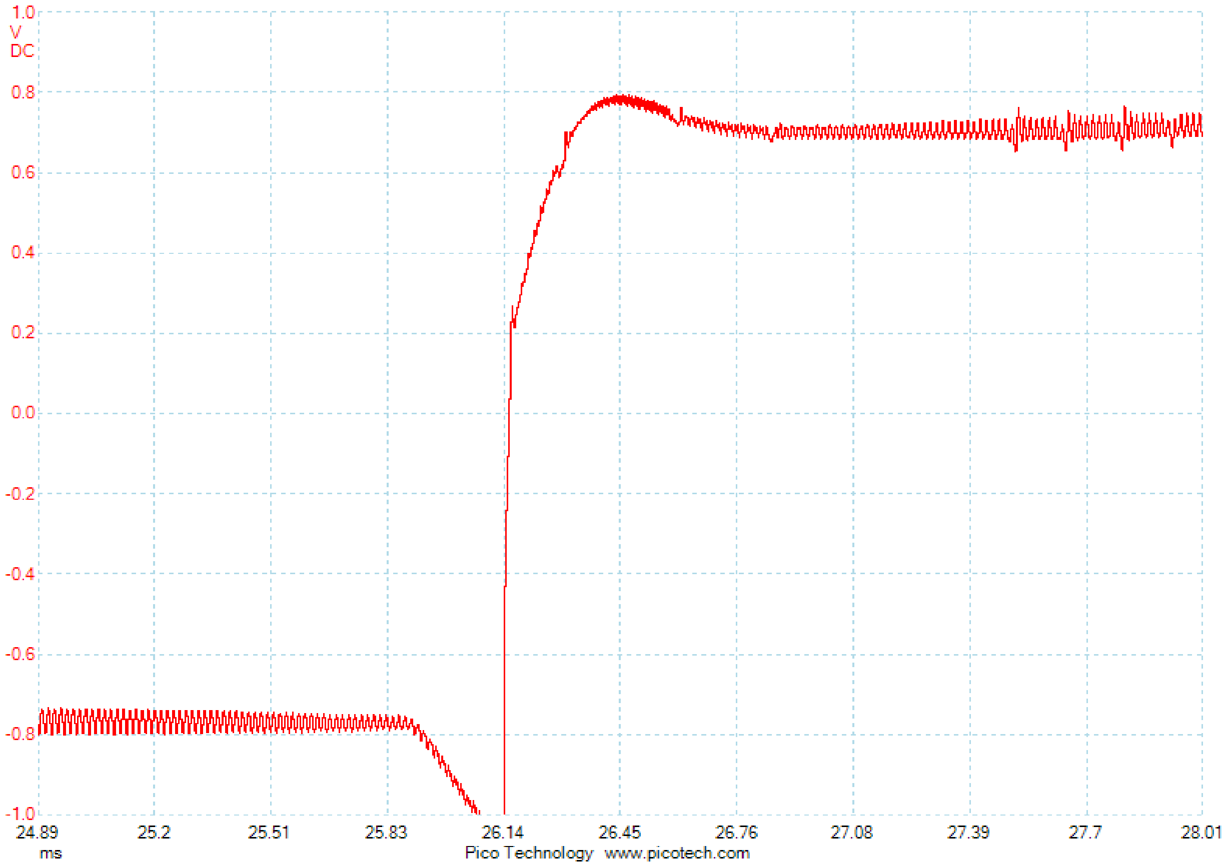

Figure 5 58 kHz component of AC arc welding waveform

The action value at 74 Hz is 9 mT, but the high harmonic content of this waveform must be considered. A very conservative Fourier-based analysis (neglecting phase) suggests that the harmonic content would lower the action value by approximately a factor of 2, to 4.5 mT.

For a welding current of 150 A, the magnetic field strength at the hand position was 126 μT. At the torso position it was 72 μT and at the head it was 50 μT. Again the torso exposure is the more significant when a factor of 4 is applied to derive a hand-specific action value, but this was 62.5 times lower than the action value even when harmonic content was considered. On this basis this machine could, in theory, use a weld current of up to 9.3 kA before the health effect exposure limit value were exceeded. If the action value were to be respected at the hand position, then the current could be increased to 5.4 kA.

Pulse welding

The equipment examined was a ProMig 501 DML pulse welder. Figure 6 shows the magnetic field waveform as the arc is struck; in this case, despite a 38 kHz excitation, there is evidence of initial instability as the arc is struck. After a few cycles the magnetic field settles to a regular 143 Hz pulse. The operator position is very similar to the AC/DC welder, with the hand being perhaps 5 cm from the arc, the torso approximately 40 and the head perhaps 55 cm from the arc.

Figure 7 shows the 38 kHz excitation in more detail from the part of the waveform recorded as the arc was struck.

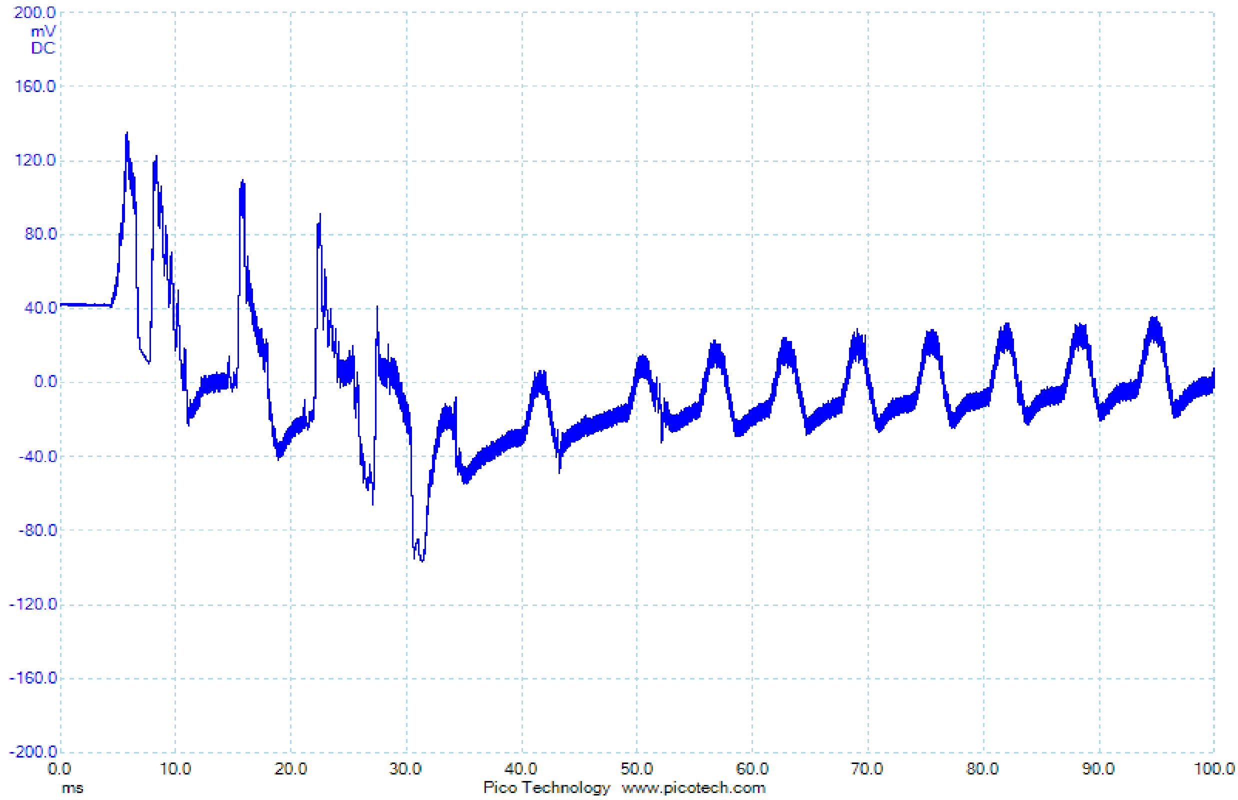

Figure 6 Magnetic field during initiation of pulse welding arc

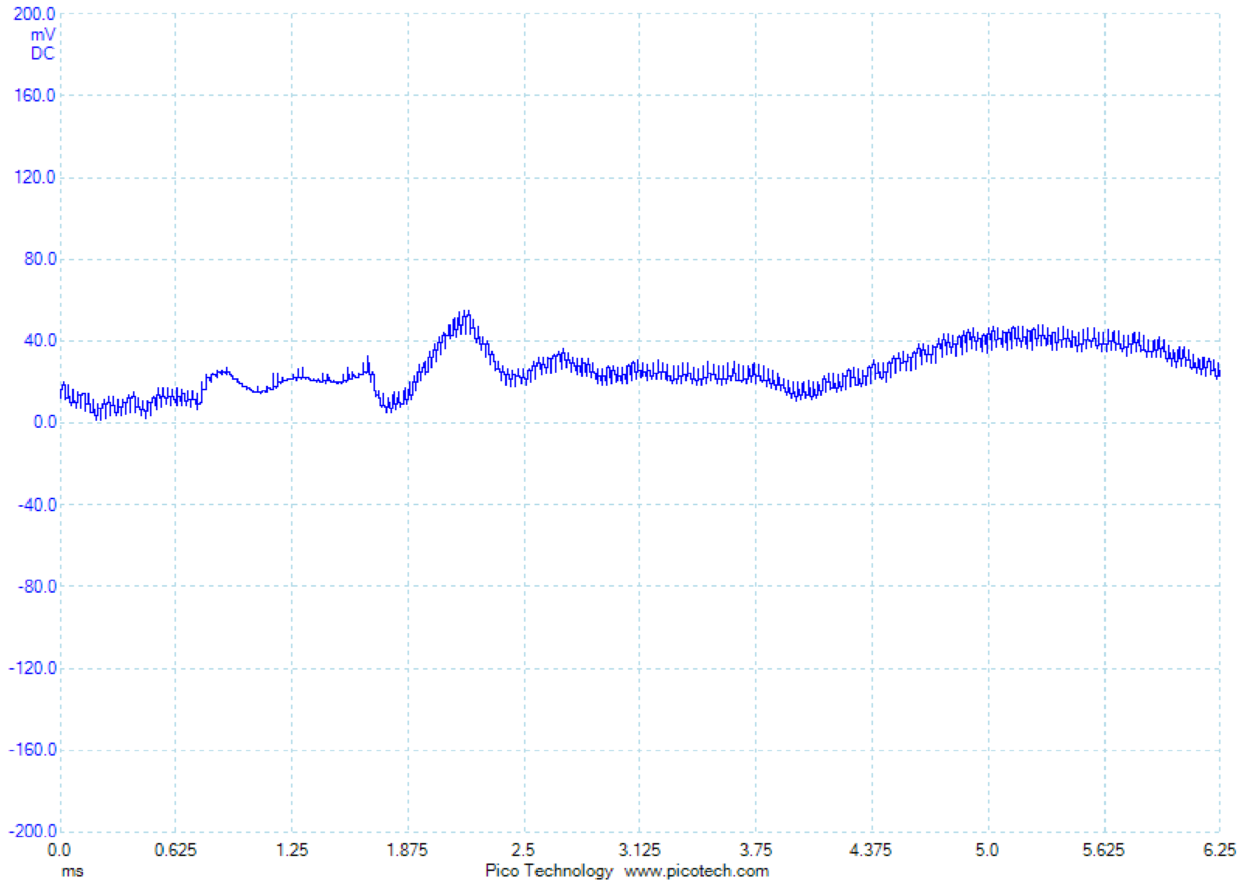

Figure 7 38 kHz excitation component of pulse welding magnetic field.

The action value at 143 Hz is 4.65 mT; the high harmonic content in the pulse would lower this to 3.2 mT (based on Fourier analysis). It was possible to measure 1.4 mT at the operator's hand position, 70 μT at the torso and 50 μT at the head. In this case, even applying a factor of 4 for an action value for the hands, hand exposure is the most significant. The machine was operating with a weld current of 242 A, and in this case it would be possible in theory to use up to 2.2 kA without the health effect exposure limit value being exceeded. If the action value were to be respected at the hand position then the maximum current that could be used would be 553 A

Drawn-arc capacitive discharge stud welder

This welder generates the arc inside the welding head, and the contracting arc draws in a spring-loaded contact. It is a "single-shot" device. The waveform of the magnetic field is shown in Figure 8. The rise time of the welding pulse is quite long; what is not shown in this figure is that after the magnetic field reached its maximum, it started to oscillate, and produced 5 cycles of a clean 100 Hz wave before decaying.

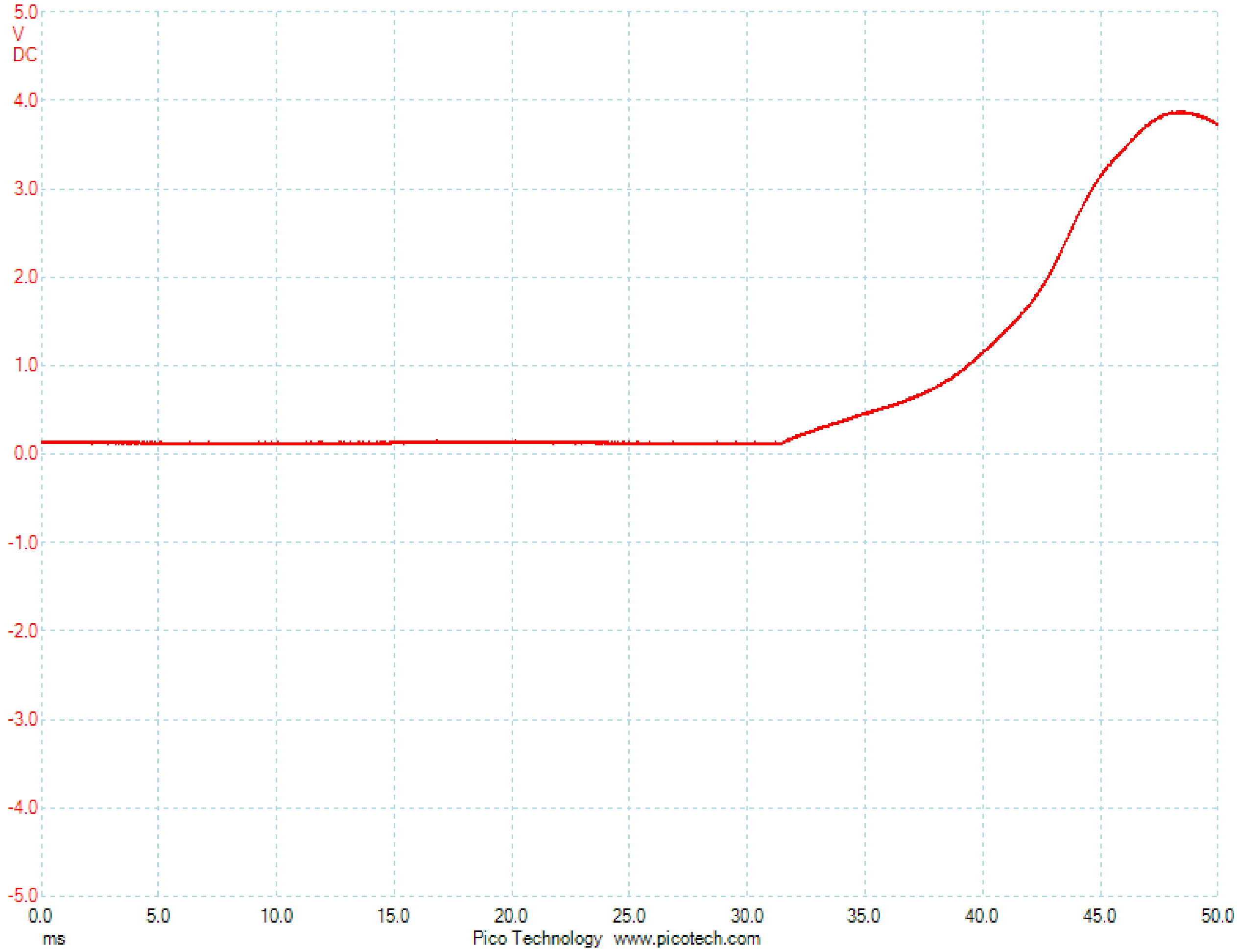

Figure 8 Drawn-arc stud welder magnetic field

For this welder, it is possible to compare exposure levels directly with the 6.66 mT action value; exposure at the position of the operator's hand was 290 μT, at the torso position it was 71 μT and at the head position it was 43 μT. The hand and torso exposures are equally significant in this case (after a factor of 4 has been applied for hand exposure), and both are approximately 90 times below the action value. It was not possible to ascertain what the operating current was at the time that measurements were taken.

Resistance welding

Single phase 50 Hz welder

A Sciaky 11.1 kA single phase resistance welder was investigated; Figure 9 shows the waveform of the magnetic field from this equipment operating on full power

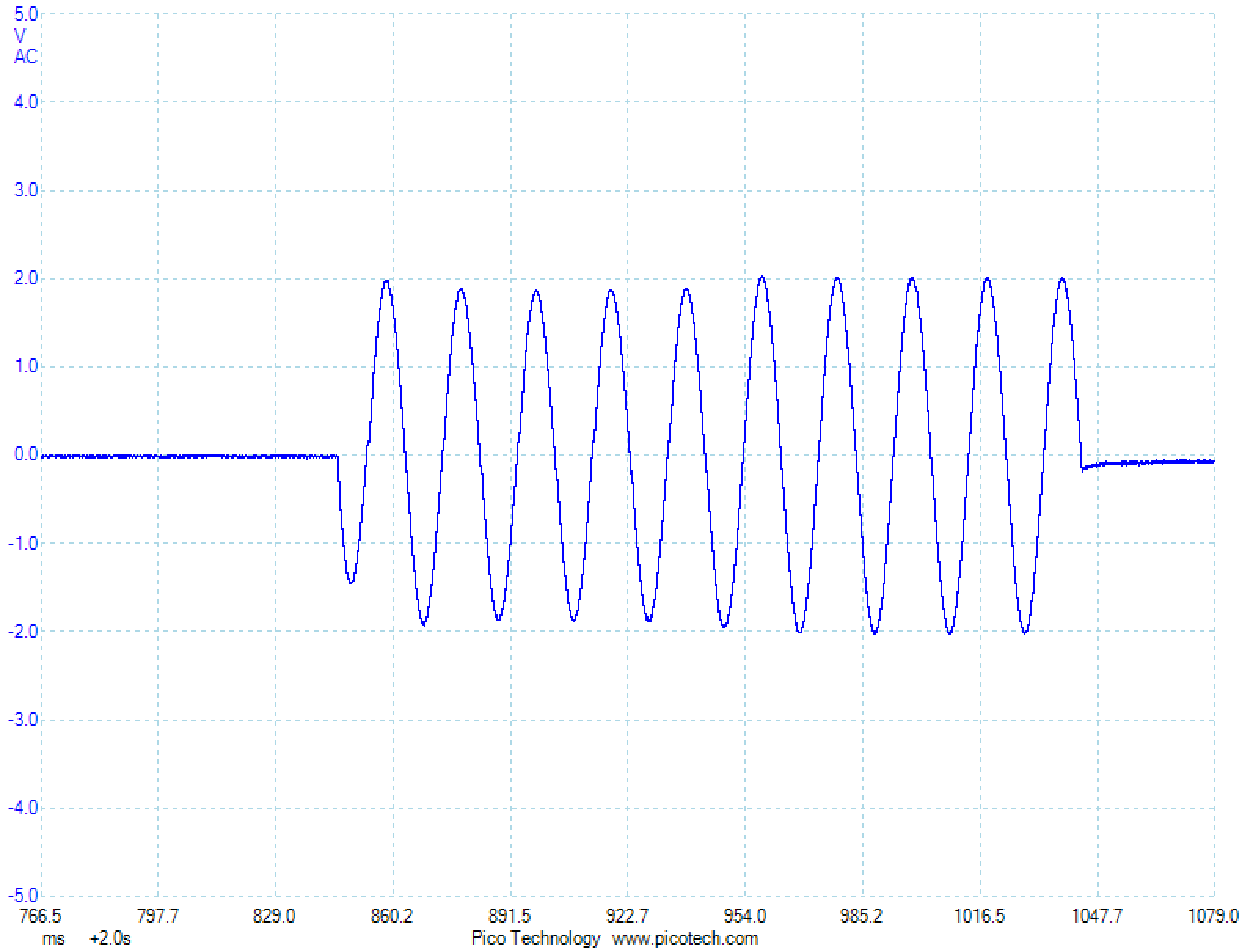

Figure 9 Waveform of magnetic field from 50 Hz single phase welder at full power

This is a very clean 50 Hz waveform, and exposures can be compared directly with the 50 Hz action value of 13.3 mT. The magnetic field at the hand position was 10.7 mT. Applying a factor of 4 to this hand exposure to take account of conduction path radius, this would mean that the same machine operating at 50 kA would not give rise to a hand exposure that exceeded the health limit values. If the action value were to be respected at the hand position, then a maximum current of 13.6 kA could be used.

Our expectation would be that for this machine, hand exposure would be the limiting factor in terms of compliance with the requirements of the EMF Directive.

There is something to be cautious of here, however. When these single phase machines operate at reduced power levels, the magnetic field waveform changes. This is because power control is achieved by switching out part of each cycle. As a result, the harmonic content increases and the effective action value that should be considered falls. Usually the emitted field strength falls more than the action value so that 100% power is worst-case, but this is not always so.

To illustrate this effect, Figure 10 shows the waveform of the magnetic field from the same welder operating at 36 % power. The distortion of the waveform can be seen.

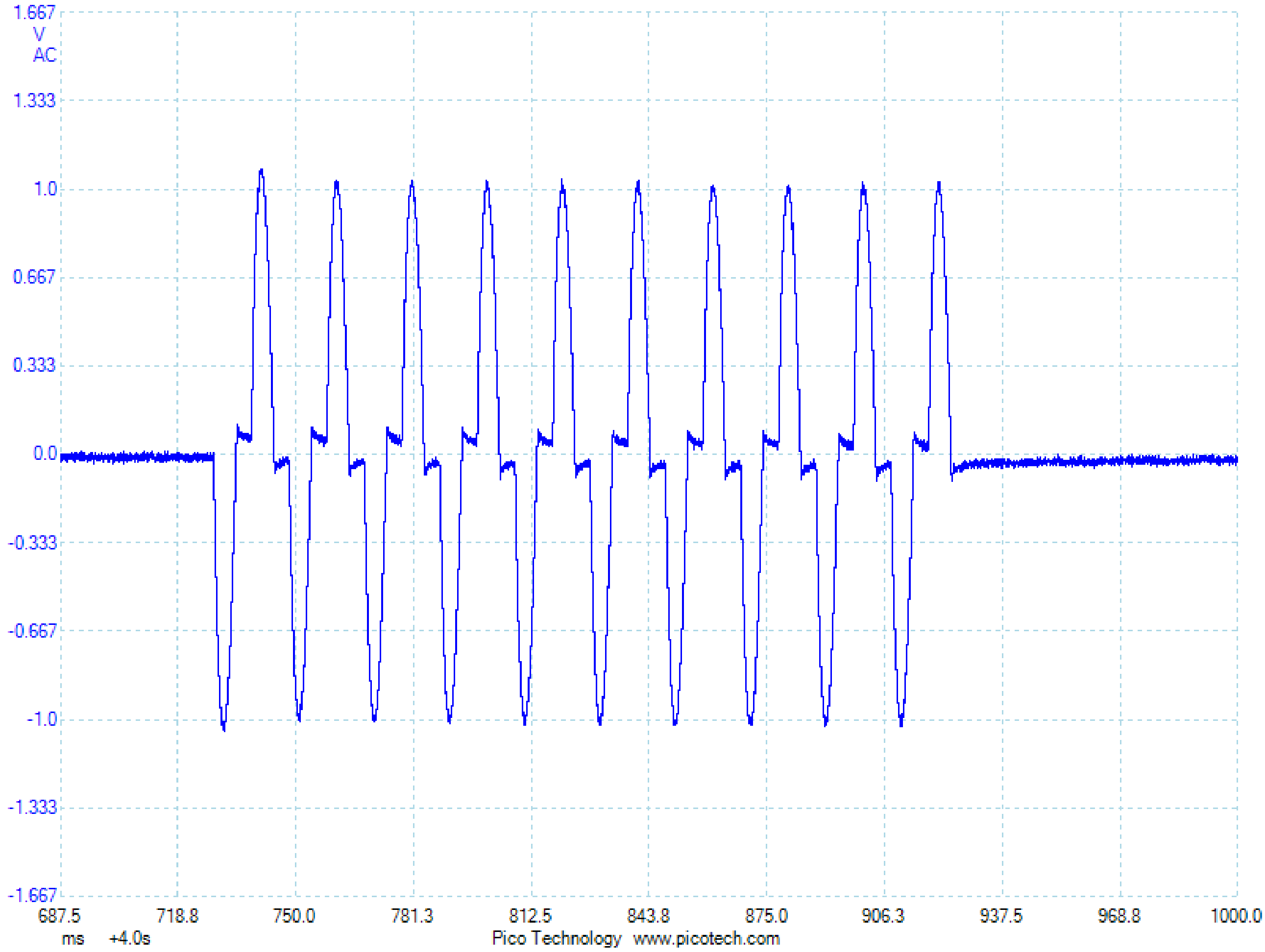

Figure 10   Waveform of magnetic field from 50 Hz single phase welder at full power

2 kHz medium frequency DC welder

This equipment consisted of a Bosch DSI 6300 power supply with a pedestal MF DC welding gun.

Figure 11 shows the welding gun, figure 12 shows a test piece in place and figure 13 shows the operator position.

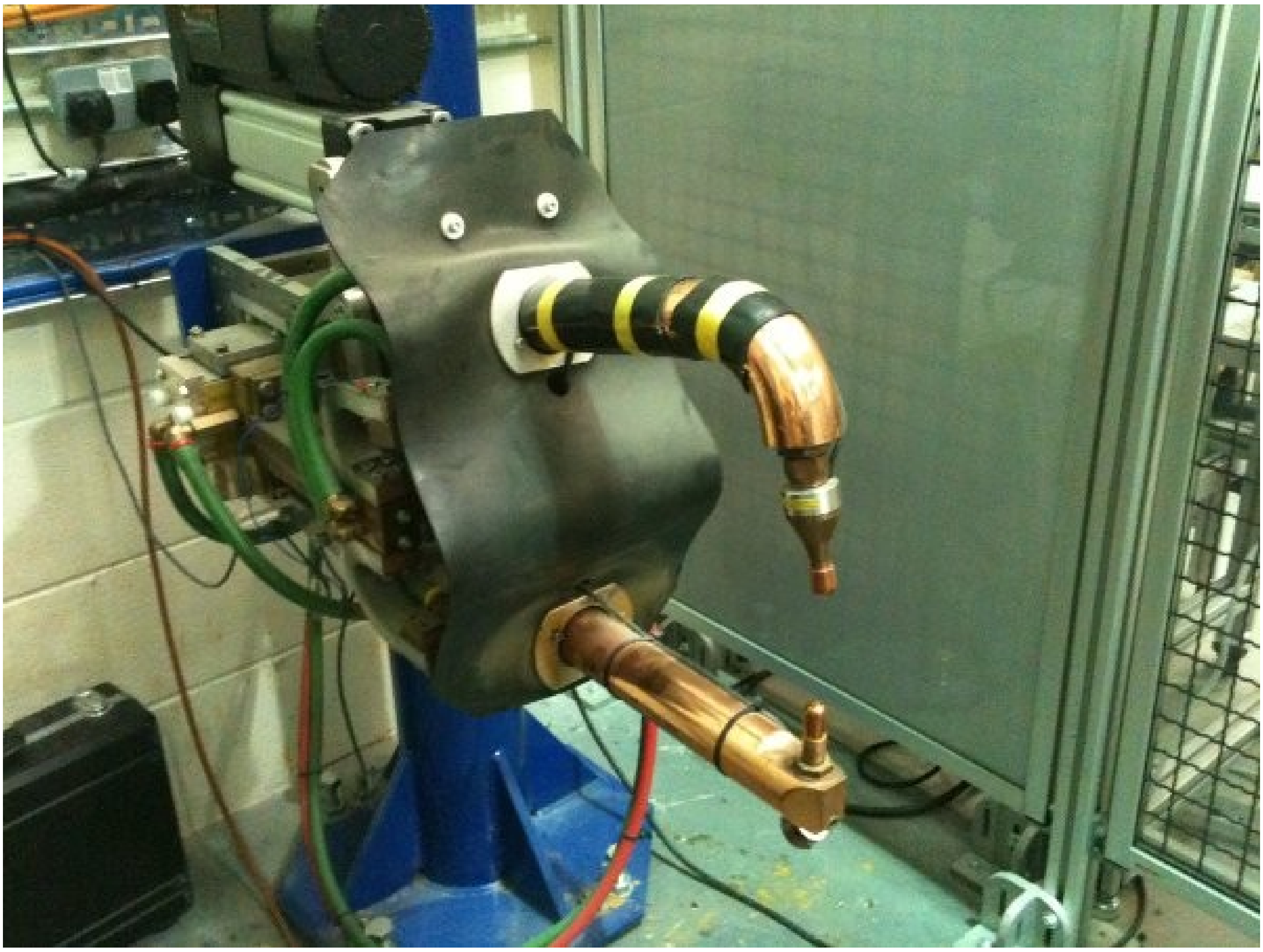

Figure 11 Medium frequency DC welding gun pedestal

Figures 12 & 13 MF DC welder test piece and operator position

This welder uses a 200 ms weld time; figure 14 shows the rising edge of the welding pulse with the 2 kHz triangular wave MF component of the field visible. Figure 15 shows the waveform during the weld, which is the 2 kHz MF signal. These waveforms were captured using a current of 10 kA and no test piece (short circuit current). Increasing the current to 15 kA and using a test piece (two 2 mm mild steel plates) did not change the waveforms.

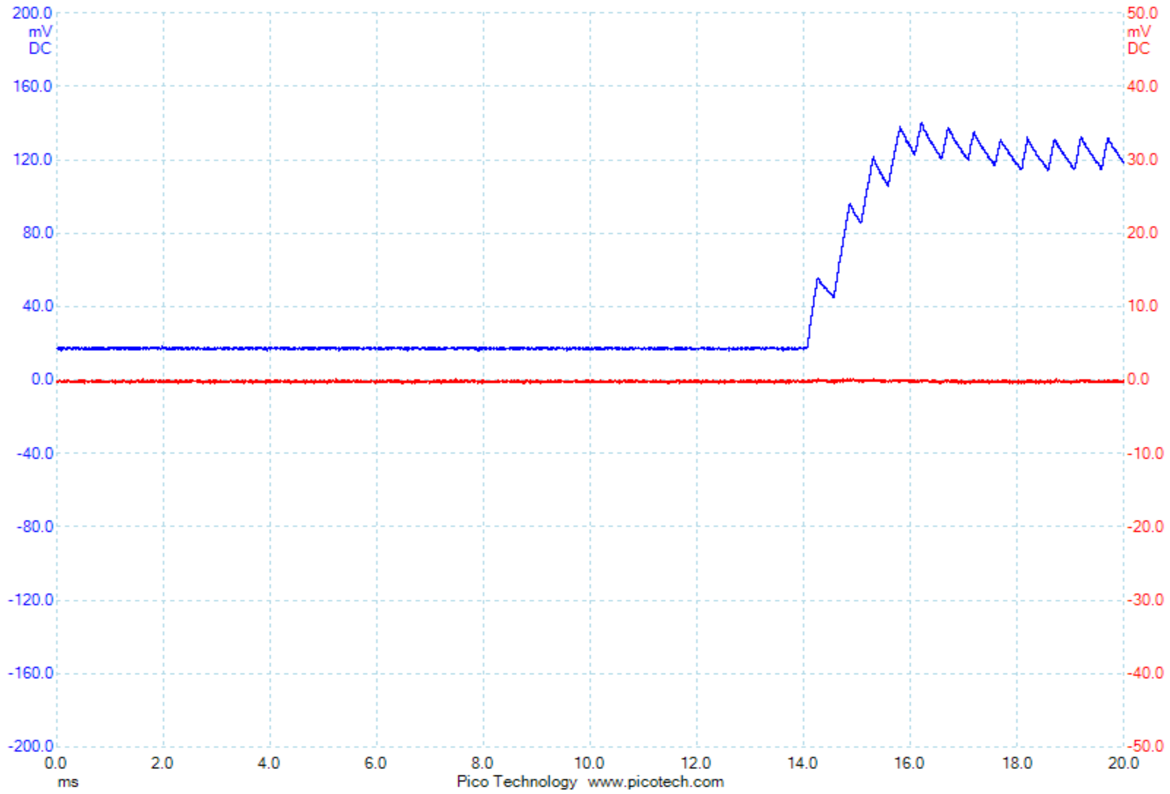

Figure 14 Initiation of MF DC pulse

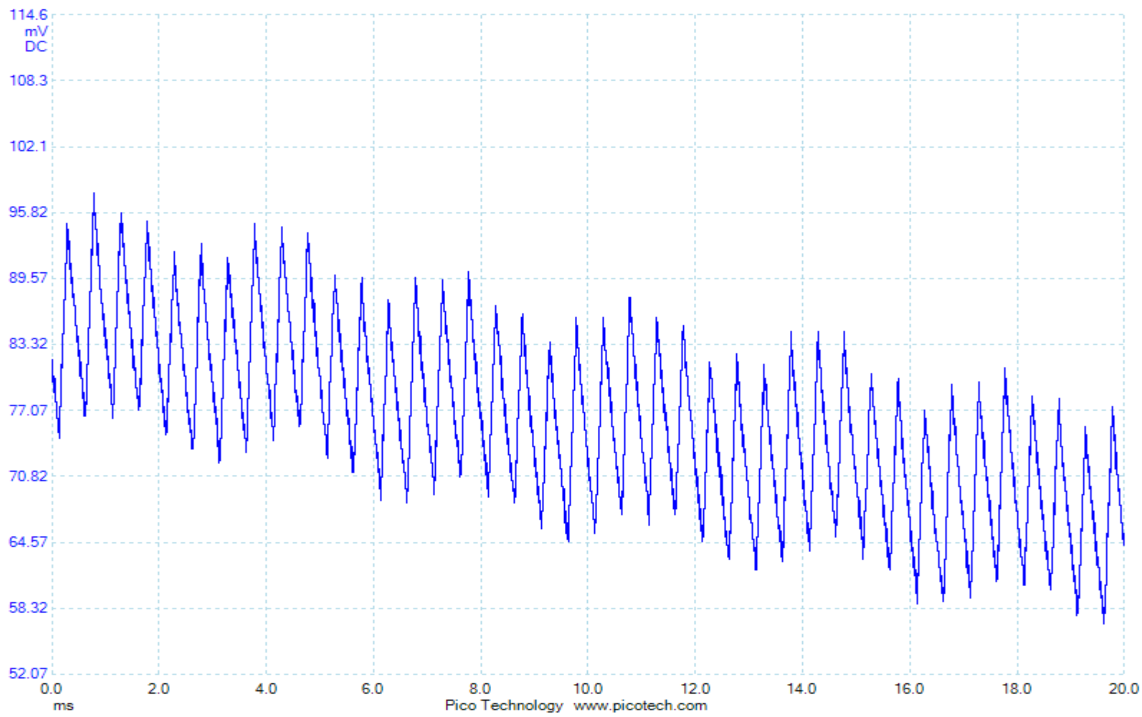

Figure `18 2 kHz signal during MF DC weld

With a weld current of 10 kA, with or without a test piece, the magnetic flux density at the hand position was 1.66 mT; at the operator's torso position it was 105 μT and at the head position it was 86 μT. The operator's hand was 16.5 cm from the weld head, his torso was 60 cm from the weld head and his head 85 cm from the weld head.

The action value at 2 kHz is 333 μT. However, this is a triangular waveform with a high harmonic content; Fourier analysis (neglecting phase) shows that there are significant harmonics at frequencies up to 10 kHz, and when these are taken into account the effective action value for this waveform is lowered to 222 μT. Whilst head and torso exposures would not exceed this level, hand exposures with a 10 kA weld current would. To meet the action value the maximum current would be 1.3 kA. Even taking into account the small conduction radius of the hand the maximum current that could be used whilst still respecting the health effect exposure limit value would be 5.3 kA.

The generator of this welder is capable of producing currents up to 36 kA, though the welding gun and transformer are limited to 25 kA.

Summary

Six different welding processes were examined at sites in the UK. A maximum theoretical current for five of the processes, such that each would still meet the action values and health effect exposure limit values, has been derived. These are as follows:

Process	**Maximum current based on**	
	Health effect exposure limit value	**Action value**
DC TIG welding	1.25 kA	506 A
AC TIG welding	9.3 kA	5.4 kA
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All the machines were examined in controlled (non-manufacturing) situations so it is not possible to draw conclusions at this stage about the effects of different materials or processes on magnetic field exposures.