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Influence of Electromagnetic Fields on Environment in TIG welding process

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TIG AC/DC zavarivanje

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This paper presents welding current influence on spreading of electromagnetic field in TIG welding process. The quality of welding is analyzed by „*Fast Fourier Transformation*" (FFT) on recorded current. Electric and magnetic field are measured using an instrument „*Macshek ESM – 100 3D Fieldmeter*" [1]. Welding current is recorded using the On-line monitoring system [2]. Recording parameters of these two devices have synchronization time on On-line interface over hardware pin and interrupt routine in LabView software platform. Scale, resolution and synchronization of measured signals are additionally analyzed in Matlab.

Utjecaj elektromagnetskog polja na okolinu u TIG procesu zavarivanja

Izvornoznanstveni čalanak

U radu se predstavlja utjecaj struje zavarivanja na prostorno širenje magnetskog i električnog polja kod TIG zavarivanja. Analizom u Matlabu „*Fast Fourier Transformation*" (FFT) nad snimljenom strujom utvrđuje se kvaliteta aparata za zavarivanje. Električno i magnetsko polje mjeri se pomoću instrumenta „*Macshek ESM – 100 3D Fieldmeter*" [1]. Struja zavarivanja snima se pomoću On-line monitoring sustava [2]. Vremenska sinkronizacija snimanja parametara ova dva uređaja određuje se hardverskim pinom na On-line sučelju i prekidnom rutinom u softverskoj platformi LabView. Skaliranje razlučivosti i sinkronizacija mjernih signala nadalje se određuje u Matlabu.

1. Introduction

Welding current has very important influence on quality of weld joint properties (mechanical, geometrical and other properties). Higher quality of weld current is defined as a higher rank machines for welding. Thus, in the TIG welding process different modes of individual welding power source appears. Modes of operation are defined by adjusting the parameters depending on the material to be welded. One of the input parameters is supplemented with material thickness of the wire and switch to select alternating (AC) or direct (DC) current circuit. In these measurements we have used two welding machines. One of these machines support only DC and other supports DC and AC welding. Using mathematical analysis procedures can be concluded which scenario more suitable for predicted task. Analysis quality is defined and presented in spectral (frequency) domain. Appearance, of lower harmonics on the recorded welding current results better properties of TIG welding machine. Current passing the conductor manifests in creation of electromagnetic fields in the environment of the working point. Electric and magnetic field are recorded in three axes and the total signal is superimposed. Right hand rule is defined by the current direction and activities of individual fields. In this paper authors present influence of current on spreading of electromagnetic field and Fast Fourier Transformation analysis quality of machines. [1 – 18]

2. Analysis of welding current with Fast Fourier Transformation (FFT)

The Fourier transformation is one of the most powerful signal analysis tools, applicable to a wide variety of fields such as spectral analysis, digital filtering, applied mechanics, acoustics, medical imaging, modal analysis, numerical analysis, seismography, instrumentation, and communications. In this scenario it is used measurement harmonic and amplitude value. Amplitude vs. time plot of a signal represents the signal in time domain. Amplitude vs. frequency plot of a signal represents the signal in frequency domain. A spectral analysis computes frequency components present in a signal and plots amplitude vs. frequency graph. Measurements like harmonic distortion are very difficult to realize in time domain by inspecting the waveform in time-scale on an oscilloscope. The same signal when displayed in the frequency domain, amplitudes of various harmonics in the signal can be easily measured. A Fourier series takes a signal and decomposes it into a sum of sines and cosines of different frequencies. Assume that it had a signal that last for 1 second, 0 < t < 1, we conjecture that can represent that signal by the infinite series:

$$f(t) = a_0 + \sum_{n=1}^{\infty}(a_n sin(2\pi nt) + b_n cos(2\pi nt)) \quad (1)$$

where *f(t)* is the signal in the time domain, and a_n and b_n are coefficients of the series *(2-2)*. The integer, *n*, has units of *Hertz (Hz) = 1 = s* and corresponds to the frequency of the wave [3] [4].

$$\int_0^1 f(t)sin(2\pi nt)dt = \frac{a_n}{2}, \int_0^1 f(t)cos(2\pi nt)dt = \frac{b_n}{2}$$

$$\int_0^1 f(t) = a_0 \quad (2)$$

FFT analysis is done in Matlab with following part of code:

```
Fs=1/TsI;
L=length(struja);
t = (0:L-1)*TsI;
NFFT = 2^nextpow2(L); % Next power of 2 from length of y
Y = fft(struja,NFFT)/L;
f = Fs/2*linspace(0,1,NFFT/2+1);
% Plot single-sided amplitude spectrum.
plot(f,2*abs(Y(1:NFFT/2+1)))
grid on;
title('Single-Sided Amplitude Spectrum of I(t)')
xlabel('Frequency/Hz')
ylabel('FFT / I(f)')
```

In measurement we have three scenarios for each machine. First machine is with DC and second with AC configurations for welding current. Welding current is recorded with On-line monitoring tool [2]. Scenarios are divided into three different distances (3, 2, 1 *m*) for later analysis of electromagnetic field (Figures 1-6).

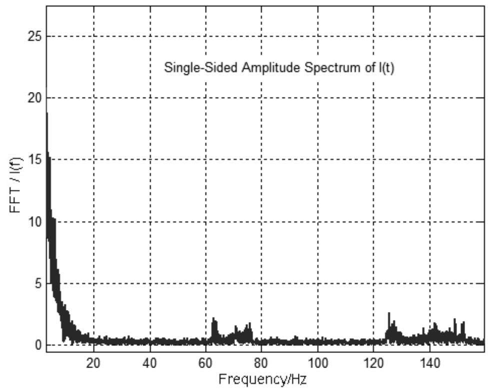


Figure 1. DC welding current FFT (DC machine) at 3*m* distance
Slika 1. FFT DC struje zavarivanja (DC aparat) na 3*m* udaljenosti

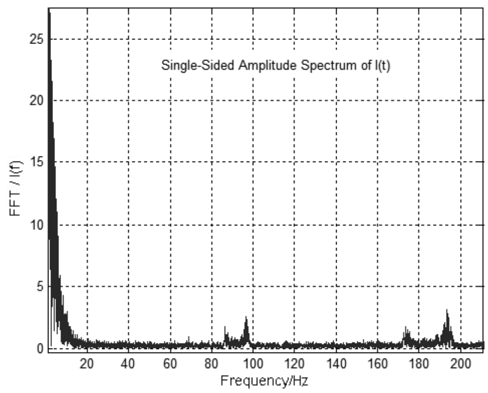


Figure 2. DC welding current (DC machine) at 2*m* distance
Slika 2. FFT DC struje zavarivanja (DC aparat) na 2*m* udaljenosti

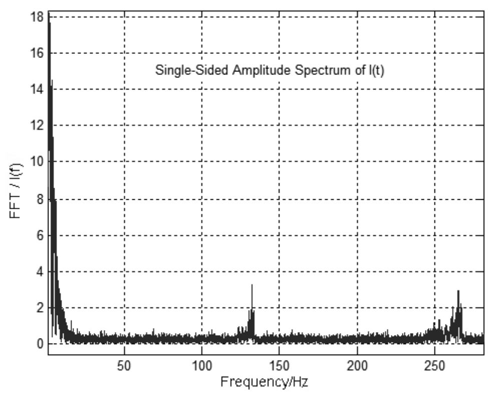


Figure 3. DC welding current (DC machine) at 1*m* distance
Slika 3. FFT DC struje zavarivanja (DC aparat) na 1*m* udaljenosti

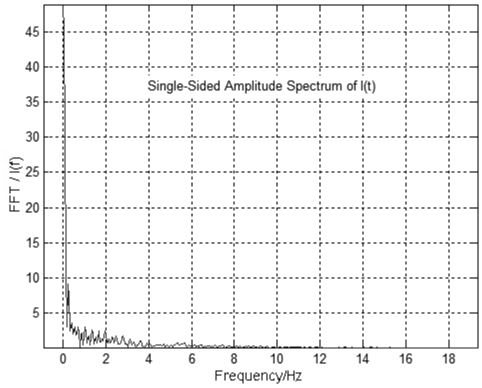


Figure 4. DC welding current FFT (AC/DC machine) at 3*m* distance

Slika 4. FFT DC struje zavarivanja (AC/DC aparat) na 3*m* udaljenosti

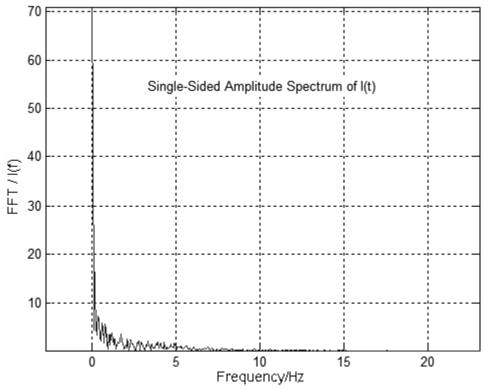


Figure 5. DC welding current FFT (AC/DC machine) at 2*m* distance

Slika 5. FFT DC struje zavarivanja (AC/DC aparat) na 2*m* udaljenosti

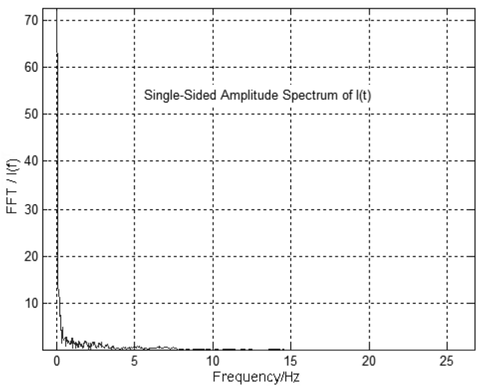


Figure 6. DC welding current FFT (AC/DC machine) at 1*m* distance

Slika 6. FFT DC struje zavarivanja (AC/DC aparat) na 1*m* udaljenosti

Welding material for DC machine scenario is the same for AC machine. Inox (stainless steel) pipe Ø40 is used for experiment and additional wire with the characteristics: (RW 1.4430/ER 316 LSI). Internal view of the welding machines for DC TIG welding is showed on Figure 7. As a protective gas argon is used to preset parameters: pressure on (8 – 10) *l/min* , and current settings for DC machine of 165 *A* (first two scenarios), 100 *A* at third case. Fundamental characteristics of the AC welding machine are shown on Figure 8.

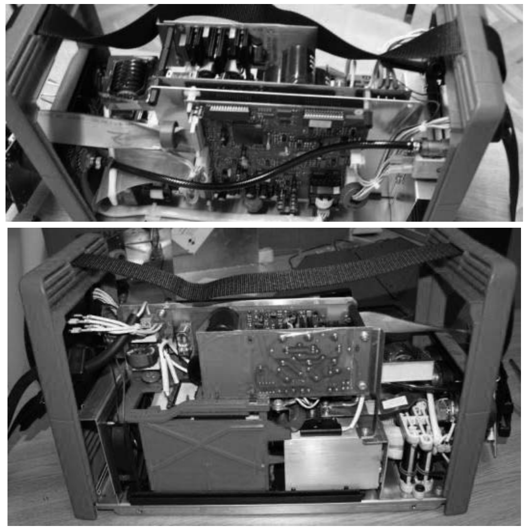


Figure 7. DC welding machine

Slika 7. DC uređaj za zavarivanje

Fronius Wels - Austria	MagicWave 2000 Fuzzy G/W/Z			
	Art.No.			4,075,072
	Ser.No.			13201416
Ulaz: 1f/50-60Hz Izlaz: DC/AC		IEC 60974-1 / EN 50199		
3 *A* / 10,1 *V* – 200 *A* / 18 *V*				
	X(40°C)	35%	60%	100%
U_0 45 *V*	I_2	200 *A*	150 *A*	120 *A*
	U_2	18 *V*	16 *V*	14,8 *V*
U_1	Osigurač	$I_{1\ max}$	$I_{1\ eff}$	S_1
230 *V*	16 *A*	21 *A*	9,7 *A*	2,2 *kVA*
IP 23		CE		

Figure 8. AC TIG machine power source display with specific data by producer [16]

Slika 8. Pločica TIG AC uređaja za zavarivanje sa specifičnim parametrima proizvođača [16]

Welding handgun in DC and AC machine is not the same. Connector for controlling the handgun has different configuration, but in principal function is the same, Figure 9. Parts of welding handgun are: wolfram wire, ceramic isolator, clamping head and button for controlling drive current and/or voltage. Second button has function for changing speed of additional wire if we use different protective gas like carbon dioxide (CO_2) for other welding method. Except for setting of the main parameters, we can change others like: diameter of additional wire, in DC+ and DC- mode raising edge or ramp with setting a specific time.

Inox (stainless steel) pipe Ø40 is used for experiment and additional wire on AC machine showed on Figure 10.

Figure 9. Welding torch
Slika 9. Gorionik za zavarivanje

Figure 10. AC welding machine
Slika 10. AC aparat za zavarivanje

3. Synchronization of measurement parameters and superposition of 3D Electromagnetic Field

Electric current plays an important role in practically all areas of life. Nevertheless, voltage and current generate electric and magnetic fields which for their part can lead to negative effects on health. The measuring instrument ESM-100 3D H/E Field Meter is a unique, patented, hand – held measuring instrument which allows easy measuring of alternating electric and magnetic fields at the same time, independent of direction and corresponding to one common point (Figure 11.). Connection with software analyzer is realized with optical RS232 cable which is separated galvanically. This way the components are isolated from interference on digital communication line.

Figure 11. H/E Field Meter
Slika 11. H/E mjerač polja

Simultaneous measurement of electric and magnetic fields in all three axes is shown in Figure 12. The first measurement zone is defined strictly with 50Hz. In this way it is visible effect of the magnetic field of the environment with defined frequency filter based on the element of the first harmonic. Second zone is frequency range of measurement sensor tuned to the frequencies from 2kHz to 400kHz. To include the whole spectrum provided that the machine may further include, we used the band from 5Hz to 400kHz. Effect of welding on the environment is more visible in the magnetic field rather than electric.

Figures 13. – 15. are electric and magnetic fields in the vicinity of the working point. Impact of electric field on the environment is very small. Peak value during welding is only 10V per meter (Figure 15.). This value is superimposed through all three axes.

Adjusting and reducing the welding current electric field is only diminished, as might be expected by changing the distance from the point of welding. Influence of the magnetic field (Figure 13. – 15.) proved to be a significant difference compared to the electric field. Measured values of maximum 1μT not harmful to human health, in parallel with the values approved in the energy legislation to 100μT.

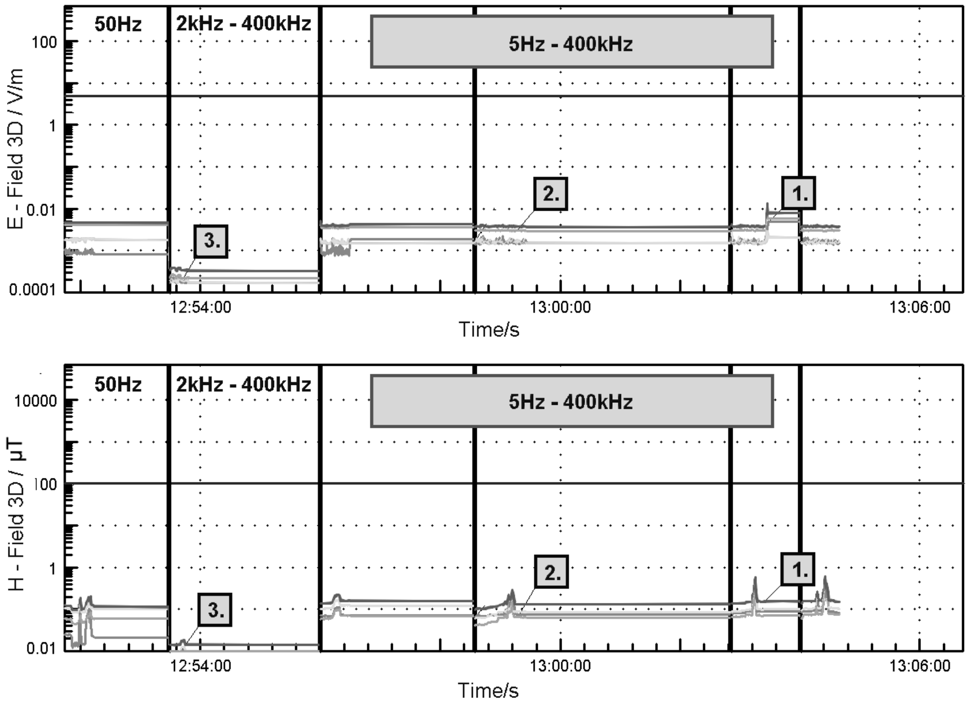


Figure 12. Overall results of the AC measurements
Slika 12. Ukupni rezultati AC mjerenja

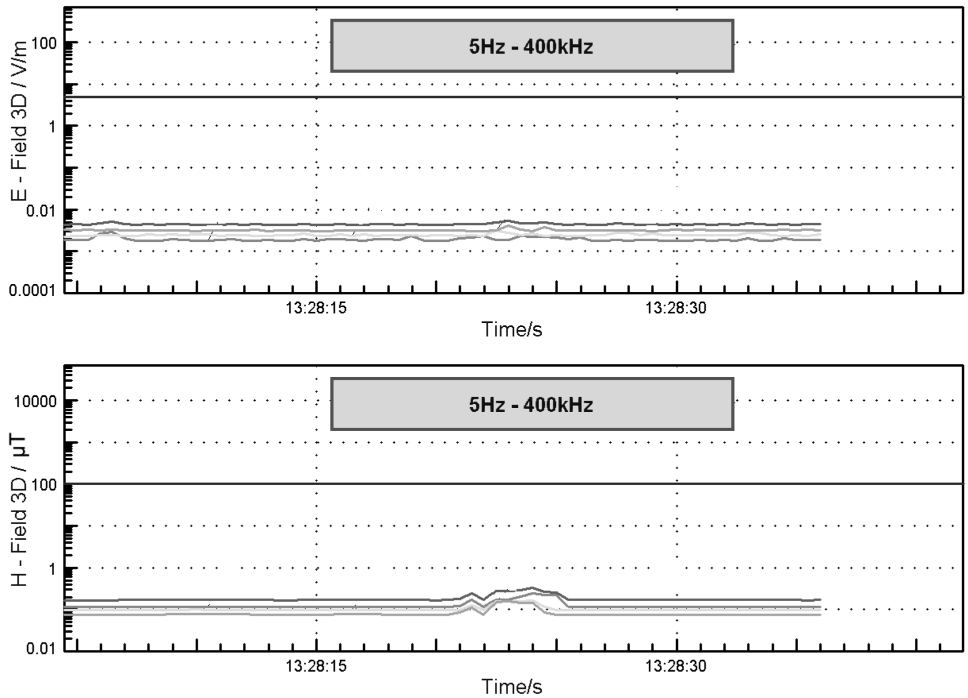


Figure 13. Electrical and Magnetic field – distance 3m
Slika 13. Električno i magnetsko polje – udaljenost 3m

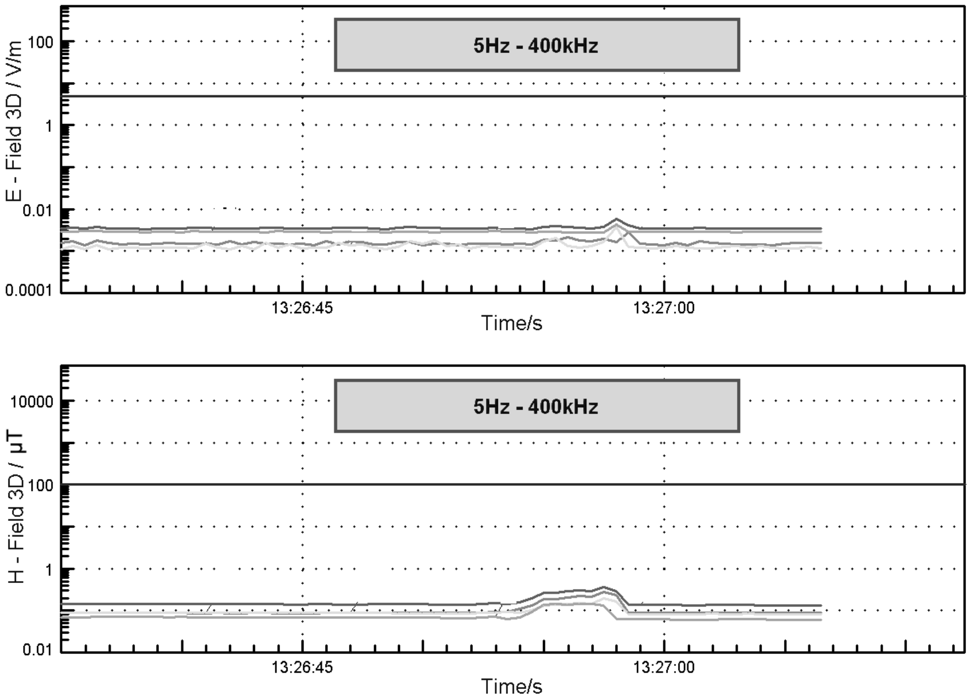


Figure 14. Electrical and Magnetic field – distance 2m

Slika 14. Električno i magnetsko polje – udaljenost 2m

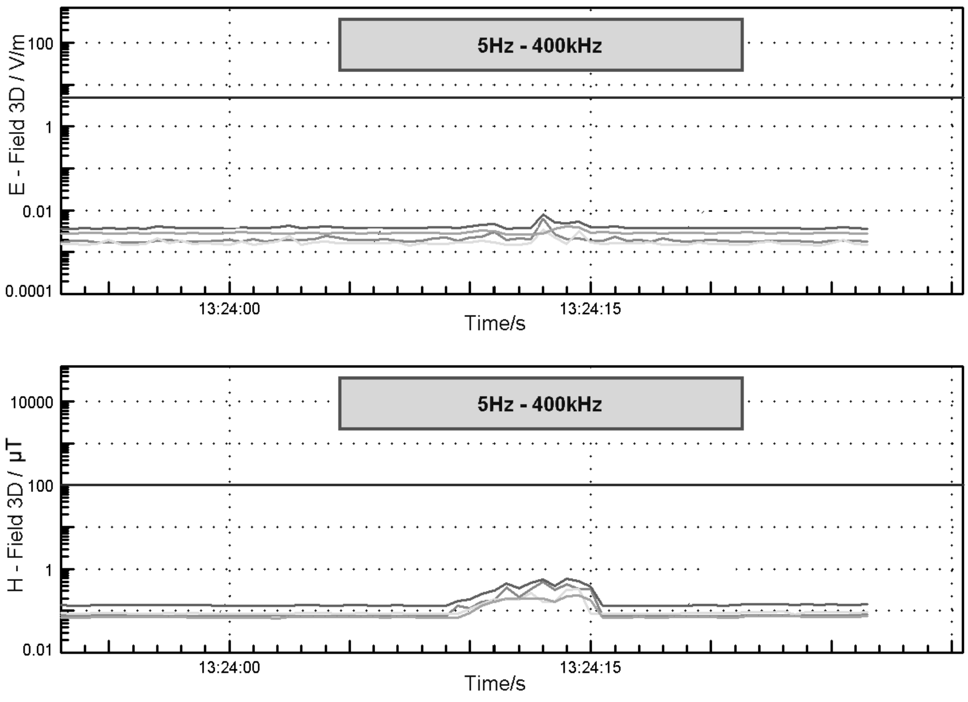


Figure 15. Electrical and Magnetic field – distance 1m

Slika 15. Električno i magnetsko polje – udaljenost 1m

In theory the relationship between the flux density, B and flux density, H can be defined by the fact that the relative permeability, μ_r is not a constant but a function of the magnetic field intensity thereby giving magnetic flux density as: B = μ H. Then the magnetic flux density in the material will be increased by a larger factor as a result of its relative permeability for the material compared to the magnetic flux density in vacuum, μ_oH and for an air scenario in welding case. Permeability of free space, (μ_o = $4.\pi.10^{-7}$ H/m) can act linearly with multiplier μ_r in system like ours with DC component, Figure 16.

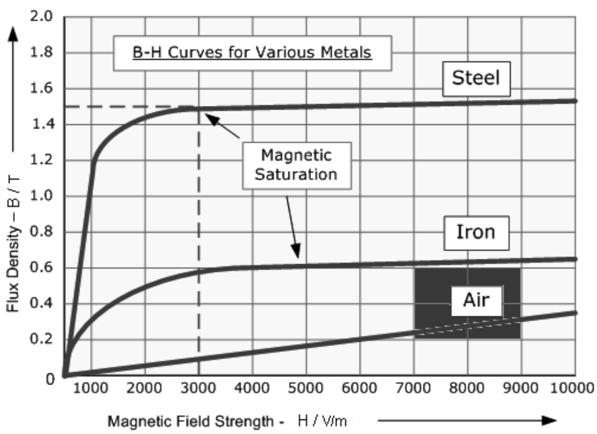


Figure 16. B – H curves for air (linearity)
Slika 16. B – H krivulja linearnosti u zraku

Magnetic field in this case is a charge which is moving parallel to a current of other charges experiences a force perpendicular to its own velocity. Just as we have defined the electric field vector **E** as the force on unit test charge at rest, so we can now define another field by the velocity – proportional part of the force that acts on a test charge in motion. To state this precisely, experiments show that the force on test charge *q* moving with uniform velocity *v* is given by:

$$F = qE + \frac{q}{c} v \times B \qquad (3)$$

where **E** and **B** are vectors that do not depend on *v*. Then **E** is electric field and **B** is magnetic field at that place [14]. Assuming that this is a real pair wire [15., *p*.165.] magnetic induction outside the conductor where $r \geq R_0$ is:

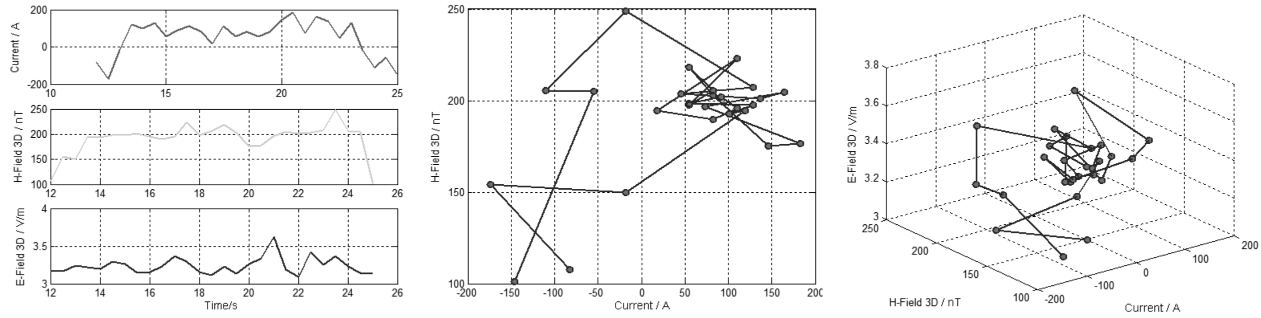
$$\vec{B} = rot\vec{A}_{v_{12}} = \frac{\partial A}{\partial y}\vec{a}_x - \frac{\partial A}{\partial x}\vec{a}_y = B_x\vec{a}_x + B_y\vec{a}_y \qquad (4)$$

Along the radial (**B**) and axial (**E**) component is defined idle of welding machines and a short circuit or load [15., *p.* 278. - 279.], expression *(5.524)* and *(5.525)*.

Figures 17 – 19 *a)* shows a set of measurement parameters that indicate the size of measurement results; current, the strength of the electric and magnetic fields. Such views are typical for DC welding machine, while Figures 20 – 22 *a)* shows the same mode on AC devices (Figure 10.) but waveforms are better and more stable in the same terms and working conditions. Figures 17 – 22 *b)* shows the 2D trajectory of magnetic field and current. Figures 20 – 22 show a faster way to the work point and more stable around the operating points. Excluded unwanted going to the negative part and move to high operating point. Figure 22 *b)* e.g. shows the nearest feature of the ideal state of no-load, short circuit and the working point under load.The right hand rule, Figures 17 – 22 *c)* shows the current, electric and magnetic fields in the 3D trajectory. Such isometrics view gives us a detailed view of the appliance and insight into the quality of welding machine.

Monitoring system [2] for recording and analysis of data has sync pinout. This pin provides a timestamp which is the initial interrupt to further analyze and synchronization in MATLAB (code for ***X*** scenario is shown below).

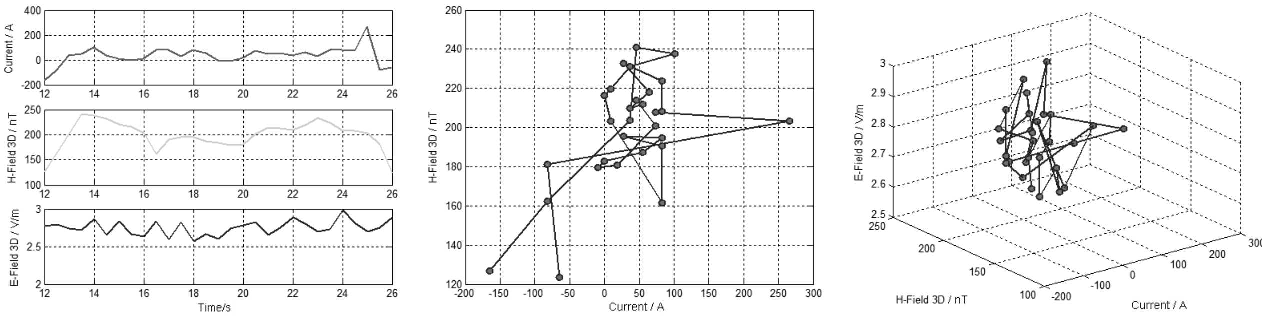
```
clear all; close all; clc;
load mjerenjeX.mat;
timeB = TsB*linspace(0,length(field)-1,length(field));
figure; subplot(211);plot(timeB,field(:,1));
      subplot(212); plot(timeB,field(:,2))
%field cuting
fieldB = field(15:34,:);
timeB = timeB(15:34);
figure; subplot(311); plot(timeI,currentI); ylabel('Current / A');
grid on; hold on;
      subplot(312); plot(timeB,poljeB(:,1)); ylabel('H-Field 3D / nT');
grid on; hold on;
      subplot(313); plot(timeB,poljeB(:,2)); ylabel('E-Field 3D /
V/m'); grid on; hold on;
xlabel('Time/s')
%print to file
file_rez = fopen(['fieldX.txt'],'wt');
for i=1:length(timeB)
   fprintf(file_rez, '%f\t%f\t%f\n', timeB(i),fieldB(i,1),fieldB(i,2));
end
fclose(file_rez);
save rezX currentI timeI timeB fieldB
figure; plot(currentI, fieldB (:,1));
xlabel('Current / A]'); ylabel('H-Field 3D / nT'); grid on;
matrica3d = [currentI fieldB];
figure; plotX(currentI, fieldB (:,1), fieldB (:,2));
xlabel('Current / A'); ylabel('H-Field 3D / nT'); zlabel('E-Field 3D /
V/m'); grid on;
```



a) *b)* *c)*

Figure 17. DC welding machine (distance from welding torch *3m)*

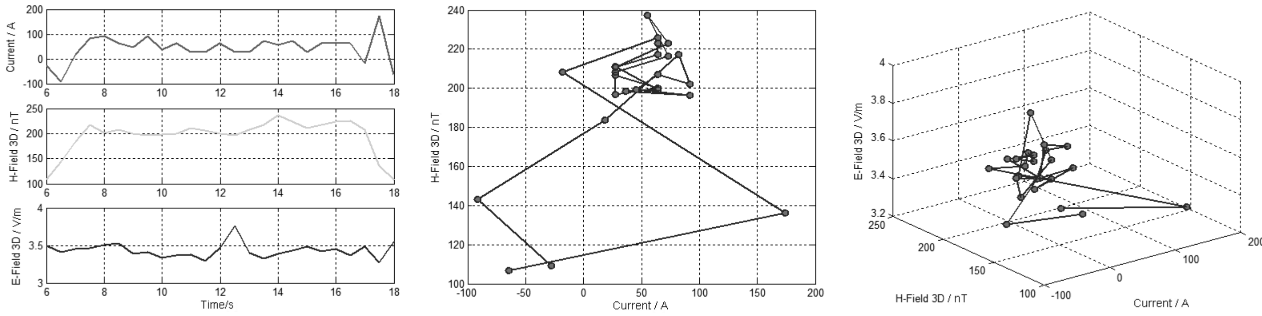
Slika 17. DC aparat za zavarivanje (udaljenost od gorionika za zavarivanje *3m*)



a) *b)* *c)*

Figure 18. DC welding machine (distance from welding torch *2m)*

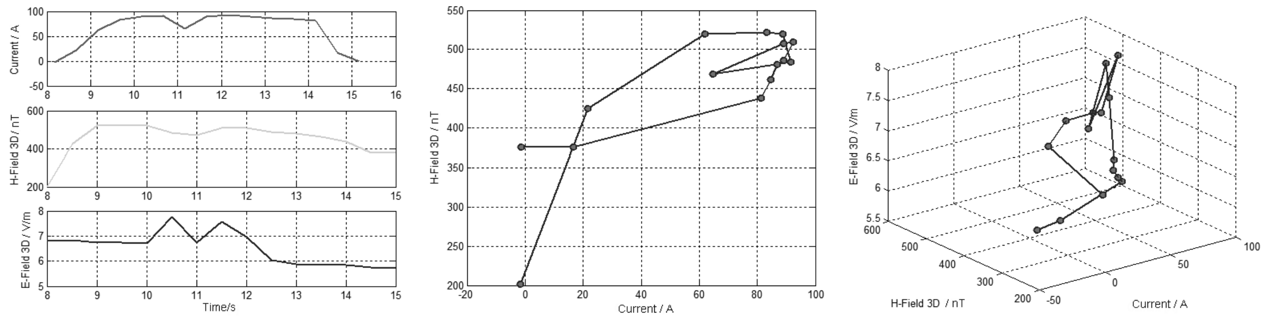
Slika 18. DC aparat za zavarivanje (udaljenost od gorionika za zavarivanje *2m*)



a) *b)* *c)*

Figure 19. DC welding machine (distance from welding torch *1m)*

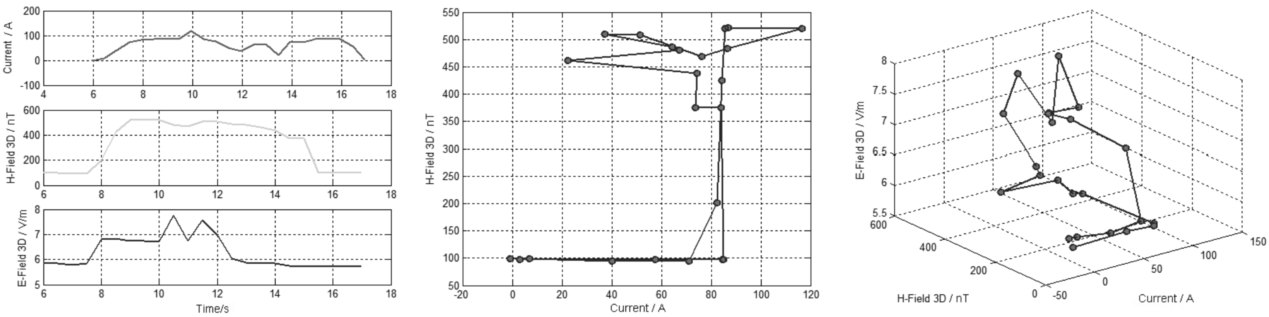
Slika 19. DC aparat za zavarivanje (udaljenost od gorionika za zavarivanje *1m*)



a) *b)* *c)*

Figure 20. AC/DC welding machine (distance from welding torch *3m)*

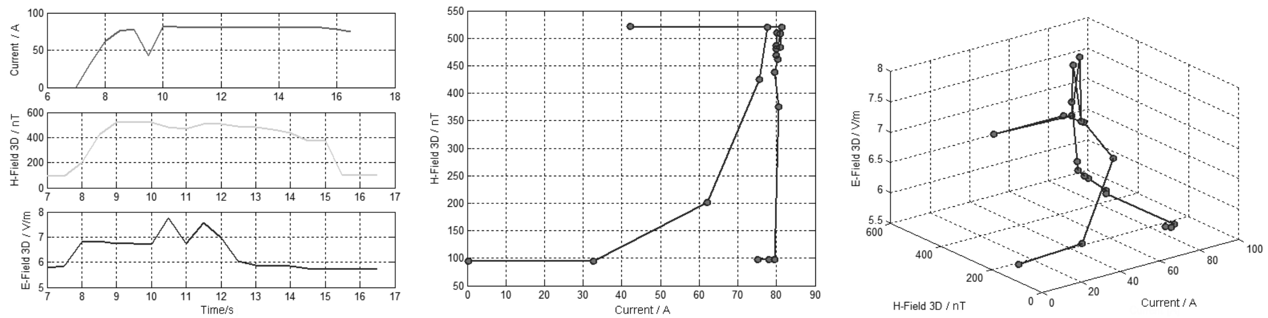
Slika 20. AC/DC aparat za zavarivanje (udaljenost od gorionika za zavarivanje *3m*)



a) *b)* *c)*

Figure 21. AC/DC welding machine (distance from welding torch *2m)*

Slika 21. AC/DC aparat za zavarivanje (udaljenost od gorionika za zavarivanje *2m*)



a) *b)* *c)*

Figure 22. AC/DC welding machine (distance from welding torch *1m)*

Slika 22. AC/DC aparat za zavarivanje (udaljenost od gorionika za zavarivanje *1m*)

4. Conclusions

This paper presents influence of electromagnetic fields on environment in TIG welding process. Using two welding machines of the same producer with same scenarios are compared with the identical set of welding parameters.

By applying FFT analysis on the welding current in Matlab the difference between welding machines is determined. Thus, in the first case (DC machine), the current response showed significantly worse than in any other case (AC machine). The appearance of higher harmonics in the first case was caused by weaker electronics. Thus, the harmonics appear on the band of 60 - 80Hz, 90 - 100Hz, 120 - 130Hz in the first segment and the second segment at a frequency of 120 - 160Hz, 170 - 200Hz and 250 - 260Hz.

In the second case can be seen a slight decrease of the curve with no oscillations at higher frequency/harmonics. The system was absorbed at 5Hz, which further contributes to the quality of welds. The observed differences in amplitude of current (first case) is somewhat less for the same default value of the welding parameters at second case.

Further analysis of the recorded data on the electric and magnetic field determined the width of the spectrum (5Hz - 400kHz) characteristic of the recording and further analysis. With superposition of all three axes of each field value of the total field was obtained and is later synchronized and processed. Synchronization is done by means of interrupt routine that activates the hardware pinout of development On-line monitoring system [2]. Such signal provides a marker in the time domain and connects the measured values of current, the electric and magnetic fields. The resulting values are then displayed in a 2D trajectory (current and magnetic fields) and knowing the rule of the right hand, displayed the 3D trajectory of current, the electric and magnetic fields. From the first case we can see irregular work in terms going into the negative part, while it is fixed in the second case on AC welding machines. Figure 22 *b)* quantitatively shows the curve that most closely describes the ideal curve of the system. We can see from the Figure 22 *c)* departure in working point of no-load and short circuit. The same figure shows the electrical properties of high-quality welds with minimal electric and magnetic field, which is convenient for the working environment.

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