CHARACTERIZATION OF MULTILAYER CORROSION BY PULSED EDDY CURRENT

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Abstract

According to the state of the art the eddy current testing (EC) has a strong application in the defect detection. The sensitivity to characterize defects and other parameters can be improved by an optimal choice of probes and operation frequency. As the same of the pulsed eddy current technique of pulsed eddy currents presents great potentialities in determination of the material corrosion. The technique showed their importance in the evaluation of the structures into multi-layer. The technique allows the detection of the defects into the 2 [3rd] and the 3 [3rd] layers. Contrary to the traditional eddy currents where the penetration is limited, pulsed eddy currents reach a depth higher than 8mm.

Electric conductive material samples were made of Aluminium and steel and heated at different temperature with variable exposure times. The aluminium and steel samples were then exposed to corrosion using an electrochemical process.

The applied NDT methods can characterize grain size changes, microstructure types, micro structural changes, hardness changes after treatment. The objective of our work is to detect some metallurgic characteristics by non-destructive methods.. The characterization of the structure modifications by pulsed eddy currents allows to detect mechanical and metallurgical parameters of materials.

Keywords: NDT, pulsed eddy current, corrosion, defect, signal treatment,

INTRODUCTION

The development of non-destructive testing has a considerable importance. Pulsed eddy current measurements is very used in the non destructive testing such the detection of defects, the measurement of conductivity, and the estimation of the thickness of coatings. The basic advantages of transient system are: firstly, the circuitry, it is relatively simple compared with that needed for broad band alternating current testing.
Secondly the single transient response contains much information. In order to extract the information, and thus, realize the full potential of pulsed eddy current testing, the signals must first be analysed
Theoretically, a transient field or an induced voltage is related from the corresponding time harmonic complex amplitude through the Laplace transform. Consequently, results from an analysis of alternating fields can be used to determine the variation of the probe signal or the electromagnetic field with time. This paper present the system design and the results of pulsed eddy current experiments performed on laboratory on multi-layered specimens. The various ways of presenting PEC data will be illustrated, such as the time based A-scan C-scan image formats .

PHYSICAL APPROACH

The pulse unit employed to drive the transmitting probe coil. The capacitor is charged quickly from a high square voltage source, the discharges are very rapid. The voltage across the probe coil rises very fast and decreases toward zero. The resulting current in the probe produces a pulsed electromagnetic field that penetrates into the steel sheet. The important characteristics of the output pulse are the height of the peak voltage and the time delay from the pulse beginning to the peak of it.
The determination of the material's parameters by pulsed eddy current is based on the measurement of the variation response of impulse excitation.Different parameters, which influenced the response, are the permeability, thickness or other anomalies...

In physical structure.
The form of induction is given by : [6]

$$\frac{B(t)}{B_{00}}=\frac{1}{(w_0\tau^{1/2})}\frac{(\cosh^2 2k-\cos^2 2k)^{1/2}}{\cosh 2k+\cos 2k}\sin(w_0-\vartheta)+\sum_{m=1}^{\infty}\frac{2}{\pi^2(m-1/2)^2}\frac{e^{-s_m w_0 t}}{s_m+1/s_m},\quad(0\le t\le t_0)$$

$$=\sum_{m=1}^{\infty}\frac{2}{\pi^2(m-1/2)^2}\frac{1+e^{s_m\pi}}{s_m+1/s_m}e^{-s_m w_0 t},\quad(t\ge t_0)$$

with parameters $k=(w_0\tau/2)^{1/2}$, $s_m=\pi^2(m-1/2)^2/w_0\tau$, and $\tan\theta=\frac{\sinh 2k-\sin 2k}{\sinh 2k+\sin 2k}$

On the other hand, if we assume that the average field follows the driving current pulse:
$B(t)=B_{00}\sin(w_0 t)$, $(0<t<t_0)$

EXPERIMENTAL APPROACH

The reception sensor detects any variation or change due to the influence of the material characteristics. This response is a measurement of the total magnetic field on the surface of material, which includes transmission and reception of fields.
The penetration of magnetic field in material undergoes a widening or a delay according to the depth. Since the incident field remains constant, any variation of the signal at the edge of reception probe is due to the eddy currents. Consequently, a balanced signal is obtained by the difference of the measured signal and the reference signal.

The resulting signal represents primarily the disturbances of the reflected field due to the anomalies. The pulsed eddy currents sensors are in differential mode (excitation-reception).The position of the reception probes are adjacent or in the center of excitation probe,[2] (figure(1)) Pulsed eddy currents methods consists of the potential difference measure at the boundaries of sensor. The realization of the sensors is very significant for the eddy currents testing.The reception probe transports the induced tension of the materials magnetization and gives the possibilities to kept and analyze pulsed eddy currents signal

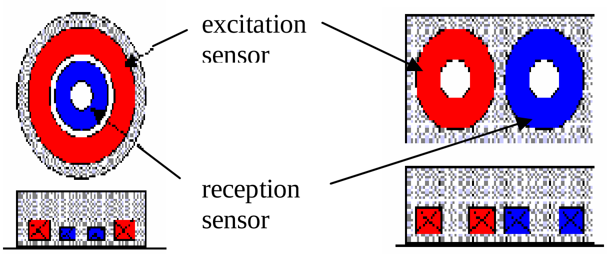


Figure1. Diagram of the probes used one controls by PEC

Measurement and analysis

The penetration limit of the Pulsed Eddy Currents (PEC) is significant, it is necessary in a first approach to determine the influence of the various parameters.
The signal obtained by the receiving probe is visualized in figure (2)

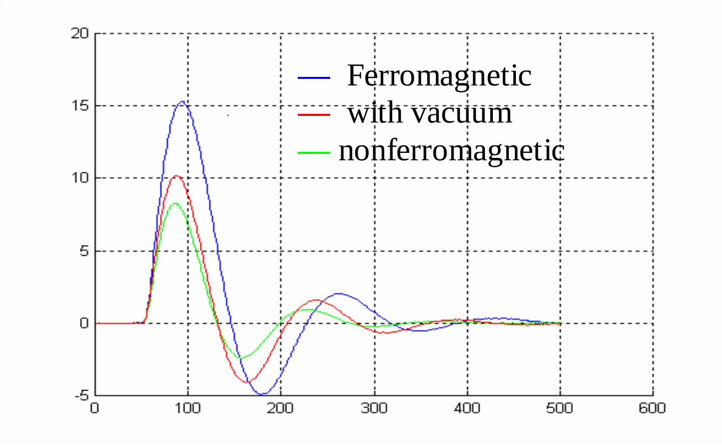
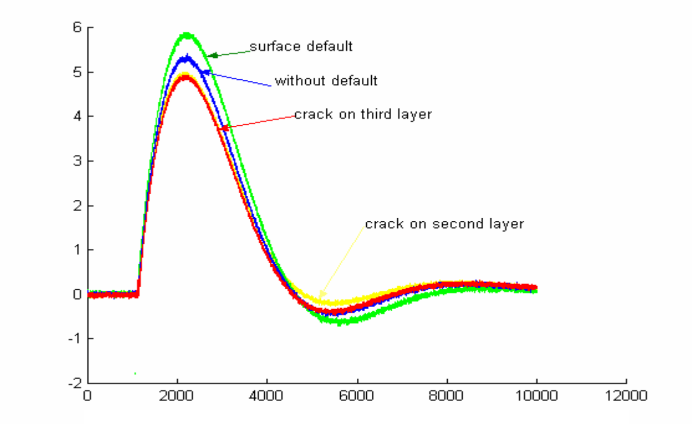


Figure 2. Response of various materials

The signals obtained on the ferromagnetic and non ferromagnetic material testing allow to note the behavior of the PEC in the presence of a driver.The frequencies and amplitude analysis allow the extraction of the information of the measured signal

Analysis of Amplitude

A significant variation of amplitude of the signal is noted on the figure (2).This variation is due to the creation of the eddy currents on the surface of the conductor. Through study is necessary to determine the various parameters influencing the variation of amplitude. We carry out modifications of certain parameters and to see their behaviours on pulsed eddy currents thereafter[3].Figure (3) shows the transient signals measured by emission - reception of coil for various typical tests parameters and particular conditions of material
The signal is a voltage measured across a reception coil, the curve can be considered as relative measurements of the tension induced into the reception coil due to the changing magnetic fields at the surface of the material. These signals, therefore, contain the total information on both the transmission and reception fields. It is immediately apparent that the signals undergo only very subtle shape and amplitude changes, even for extremely different test conditions



Figure(3) A-Scans representing flaw transients

The results found [1] have been reproduced in these experiments to show the distinctive features of the A-scans and to illustrate their potential for discriminating the different locations of the thickness .As expected, thickness in the first, is equal to the second and the third layer
While scanning different pieces, one will eventually encounter several structural variances with crack or other flaws, making the inspection more complex [4]. PEC signals are extremely sensitive to the smallest amounts of plate separation [5]. Another common noise source is the constant variation in the lift-off distance between the probe face and the surface. Substructure changes such as metal thickness increase due to the encounter of stringers also affect the signals differently.

Samples

Calibration test specimens were constructed from 2 mm thick Aluminium three 50 mm x 210 mm with crack, and one with different depth striated, this sheet was placed another. By inverting this combination, the specimen simulates thinning on the top of the second layer and third.A similar approach was taken to simulate varying lift-off distances from the probe to the surface

Behaviour of the lift-off

The lift-off indicates universally the effect of separation of the sensor compared to the surface of the part, above of which it evolves. The lift-off represents a disadvantage for measurement, because the interpretation of the result becomes very difficult (fast decrease of the electromagnetic fields in the air), but it can be an advantage to detect the uniformity or measuring by the insulating coating

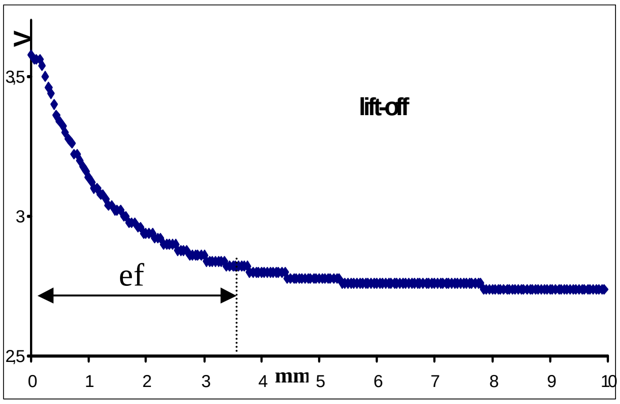


Figure4.Variation of amplitude with Lift off

One taking account of the variation of distance between the probe and the object figure (4).

We notice an exponential fall. This variation is due to the weakening of the eddy current.

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We can exploit this curve for measuring the isolating coating; the thickness of the coating can be measured until the distance **ef** and to reduce the effect of the lift-off. We work at certain distance from the sample.

Influence of Defect:

For defects located at various depths, the result obtained by PEC indicates a variation of the amplitude, more the defect is deep, more the signal is significant ., figure(5a,5b) the creation of the PEC is weak, that is due to the lack of metal on the surface as to simulate corrosion in real case. We can make a difference between the surface defects and the deep defects by the behavior of the signal (amplification or attenuation of the signal compared with the state without defect).The significant remark in this case is the depth of detection by this method. If the defect is located into the second or the third layer, we notice that the amplitude increases according to thickness added in figure (6a).

Significant parameters to be considered are the of influence of thickness on the signal and the position of defect (6a,6b)

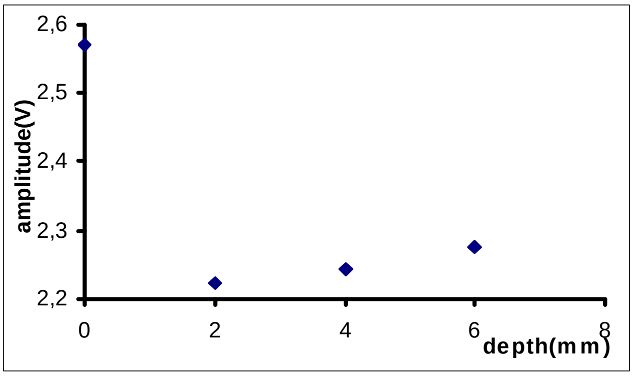


Figure5a. Variation of the amplitude in function defect depth

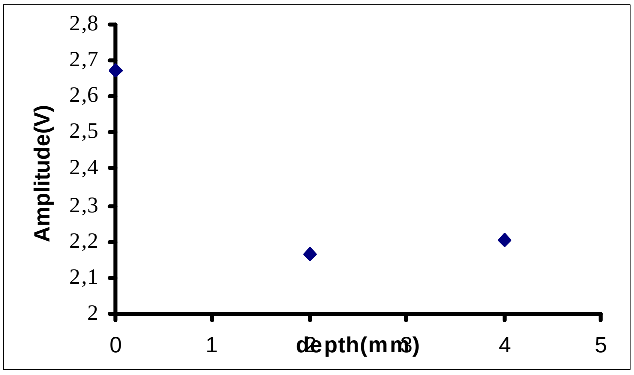


Figure5b.Variation of amplitude according to the defect depth

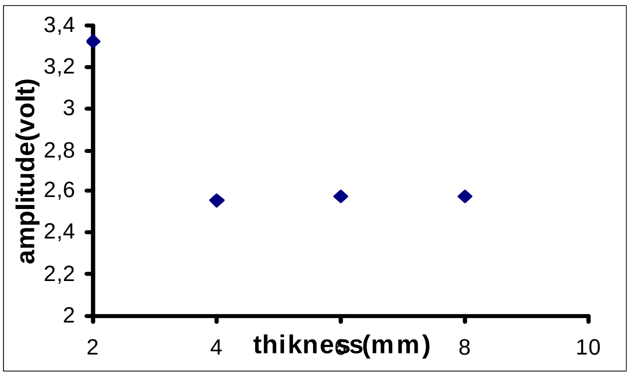


Figure6a. Variation of the surface amplitude defect according to thickness

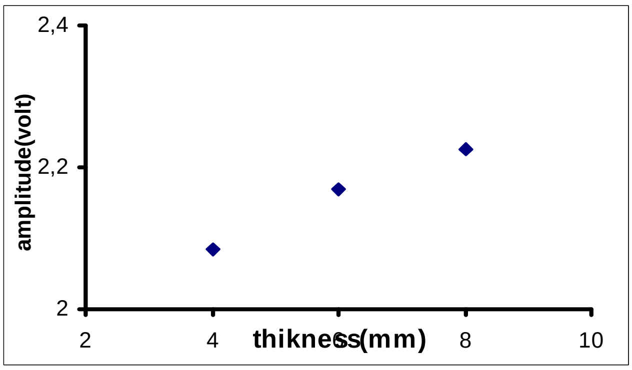


Figure6b. Amplitude variation of defect on 2 ^{2nd} layer according to thickness

Influence of Defect Size:

By Pulsed eddy currents it possible to detect defects located at various depths into the case of multi-layer. In this case we study the influence of the defects size. Same defects were tested where the length and width are constant but different size

The result obtained shows that:

More the defect is large more the amplitude is significant (7-a, 7b).

In more one notices that the amplitude is more significant for the ferromagnetic, due to the permeability influence figure (2),

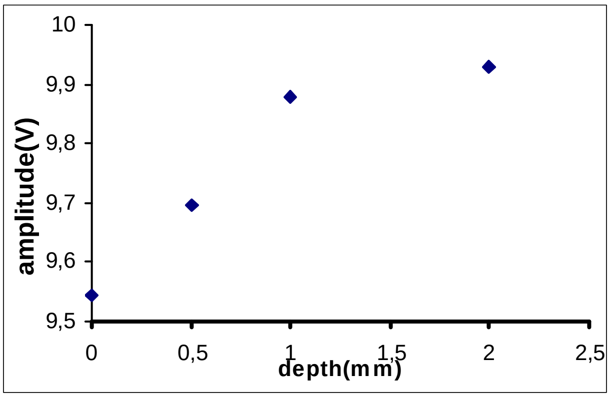


Figure7a. Variation of defect depth for 31A008

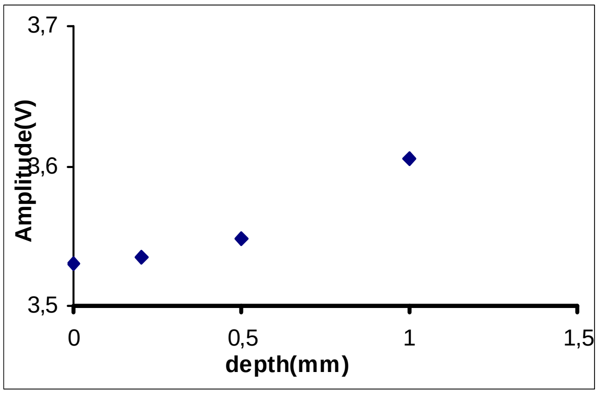


Figure7b. Variation of the depth pour le 29A029

Representation in Two Dimension of the Defects

Generally, in the non destructive testing, the A-Scan does not allow the diagnostic of the sample defect. In order to highlight behaviour in the detection of the defects (crack) at various depths, the image obtained by C-Scan is important

Time gates can be used to select certain portions of the A-scan data for analysis and can be generated for a portion of the A-scan which corresponds to a range of depth in the specimen.

The tension measured at the edge of reception sensor of the pulsed eddy currents is done by measuring the resulting field (incidental and reflected), the amplification or the attenuation depends on the electric and the magnetic parameters of material.

The presence of an anomaly in the structure of the material influences these parameters. The resulting field is disturbed and then the amplitude variation.

In our case, we carried out the testing on fissured samples with the various depths compared to inspection surface.

The inclusion defect detection simulated by three types of materials with different conductivity covered by an aluminium layer. The results obtained confirm that more the defect is deep more the answer is weak as it is translated by the image figure (8a, 8b).

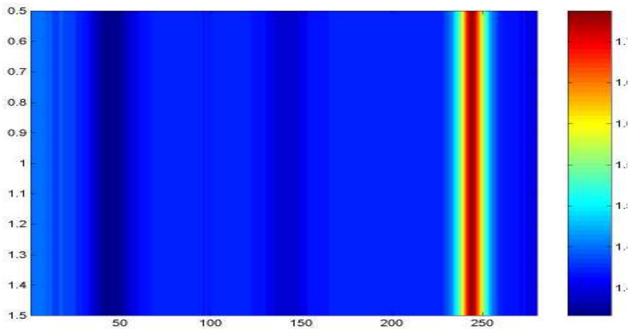


Figure8a. Representation of defects locates at different depth in 2D

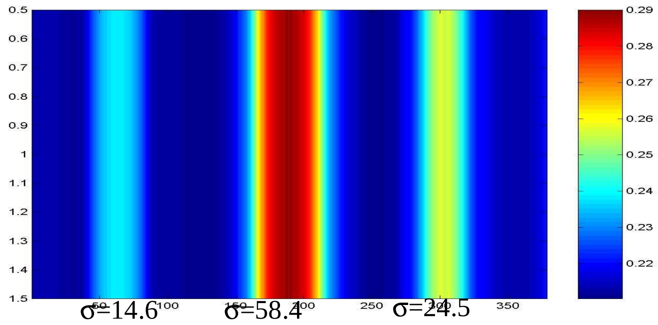


Figure8b. Representation of inclusion defect simulated by three type of conductivity

The dimension of defect represented by the image obtained by C scan is superior to the real size of defect due to the edge effect.The focusing of the magnetic field can be to minimise the edge effect

Probe Impedance

The pulsed eddy current can be calculated as impedance variation. The impedance measure was got by the signal envelope and the zero point of the signal.

The pulsation measure of the signal will be done by the passage by zero with the time axis.
The figure 9 allows calculation of this pulsation(Table 1).

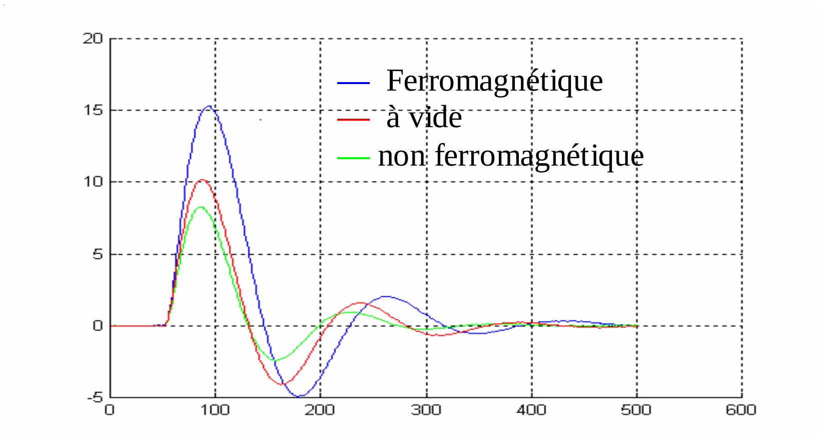


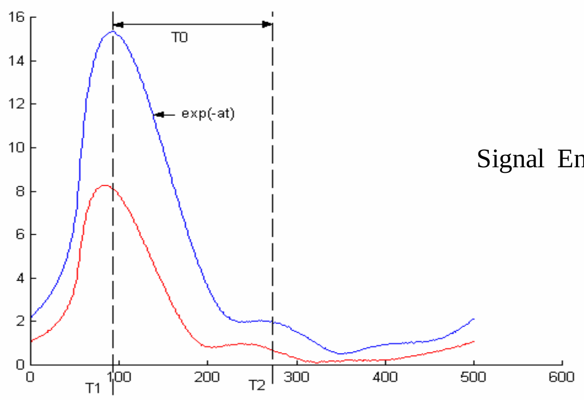
Figure9**: S**ignal of Material

T(μs)	455.5	396.012	413.594
½ T(μs)	292.666	262.050	263.570
ΔT(μs)	-29.096	1.52	-
ω (k rad/s)	13.79404	15.866148	15.191674

Table 1

Envelope Detection

The envelope detection is used to determine the amortize coefficient α.The Hilbert function allow to determinate the signal envelope. The figure 10 represents the signal envelope without presence of material and with a ferromagnetic sample



Signal Envelope of Hilbert Function

The amotize coefficient α will be done by the relation :

$$T_0 = T_1 - T_2 = \frac{1}{\alpha}\ln\left[\frac{V(T_1)}{V(T_2)}\right]$$

$$\Rightarrow \alpha = \frac{1}{T_0}\ln\left[\frac{V(T_1)}{V(T_2)}\right]$$

For the capacité C=1µF. The results are

	T_1 (µs)	T_2 (µs)	T_0 (µs)	$V(T_1)$ (Volt)	$V(T_2)$ (Volt)	w (krad/s)	α	R(mΩ)	L(mH)
ferromagnétique	200	317.6	117.6	15	2.20	13.79404	-1.570789	17.357	5.525
non-ferromagnétique	200	272	72	6.915	-0.798	15.866148	-1.570786	12.478	3.972
empty	200	300	100	8.899	-3.510	15.191674	-1.570788	13.672	4.333

Tab 2

This result is important and we allow analysing a sample treated as classical eddy current method.

CONCLUSION

A pulsed eddy current technique presents great potentialities in the development of the non destructive testing applications of materials in particular in aeronautic domain and the aluminium inspection .In this work we have studied the influence of the main parameters used in the eddy current and give the optimum information on the NDT PEC.

The sensitivity to the defects and other testing parameters can be modified by the design of the probe. The reception coil transports the induced tension of the materials magnetization and gives the possibilities to analyze pulsed eddy currents signal. The technique showed their importance in the evaluation of the multi-layer structures in particular in the determination of the corrosion in the substructure. Also we have studied the defects sensitivity in the inspection by the pulsed method and we have showed the detection of the defects into the second and third layers. The detection of the position defect is conditioned by the thickness of the sample. The penetration of PEC is very deep. The decrease of the magnetic field in the presence of the various mediums is confirmed for the pulsed eddy currents, this decrease is exploited for the measurement of isolated coating and detection from the defects.

In the future we can use the calculus of the impedance in the PEC and analyse the problem as the same manner.

References

1- A. Le Blanc , M. Piriou, Detection and characterisation of defect by pulsed eddy current, 1997 COFREND Congress on NDT-France

2- C.V.Dodd and W.E.Deeds
Analytical solutions to eddy current probe-coil problems, J. appl phys vol 39 no6 pp 2829-2838

3- D.L.Waidelich
Pulsed eddy current testing of steel sheets, Eds American society for testing and materials,1981,pp367-373.

4-- G.Birnabaum,G.Free,Eddy current characterization of materials and structures. American society for testing and materials, ASTM special technical publication 722

5- J.Bowler et M.Johnson ,Pulsed eddy current response to conducting half-space IEEE transactions on magnetic published may 1997 volume33 N^0 3 p2258

6- S. H. Kim ,Calculation of pulsed Kicker magnetic field attenuation inside beam chambers January 8, 2001