

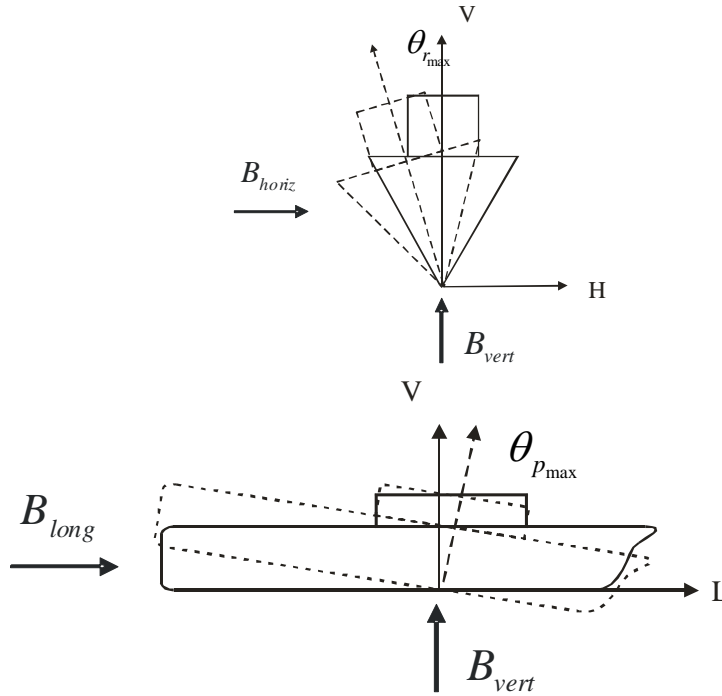


Technical Note

GENERAL ROLLING FIELDS

Sherbrooke Consulting, Inc.

The Tech Note - Calculating Rolling Fields shows how to treat the rolling ship problem as a sequence of one DC problem and two AC steady state problems. The Tech Note – Superposing Rolling Fields shows how the solutions are superposed to yield the time dependent fields such as signatures, etc. for a ship rolling in a static magnetic field on a North-South heading – i.e., no athwartship or longitudinal component of field. This tech note generalizes the problem to three axis fields (vertical, athwartship, and longitudinal) and three axis motion (roll, pitch, and yaw).



For a ship with a maximum roll angle $\theta_{r_{max}}$, a maximum pitch angle $\theta_{p_{max}}$, a (circular) roll frequency ω_r , and a (circular) pitch frequency of ω_p in a magnetic field of density B_{horiz} , B_{vert} , and B_{long} , the driving fields are given by:

$$B_H(t) = B_{horiz} \cos(\theta_{r_{max}} \sin(\omega_r t)) + B_{vert} \sin(\theta_{r_{max}} \sin(\omega_r t)) \quad (1)$$

$$B_V(t) = B_{horiz} \sin(\theta_{r_{max}} \sin(\omega_r t)) + B_{vert} \cos(\theta_{r_{max}} \sin(\omega_r t)) + B_{long} \sin(\theta_{p_{max}} \sin(\omega_p t)) \quad (2)$$

$$B_L(t) = B_{long} \cos(\theta_{p_{max}} \sin(\omega_p t)) \quad (3)$$

Equations (1) – (3) may be expanded in the usual power series. For small angles, manipulation and truncations leads to:

$$B_H(t) = B_{horiz} \left(1 - \frac{\theta_{r_{max}}^2}{4}\right) + B_{horiz} \frac{\theta_{r_{max}}^2}{4} \cos(2\omega_r t) + B_{vert} \theta_{r_{max}} \sin(\omega_r t) \quad (4)$$

$$B_V(t) = B_{horiz} \theta_{r_{max}} \sin(\omega_r t) + B_{vert} \left(1 - \frac{\theta_{r_{max}}^2}{4}\right) + B_{vert} \frac{\theta_{r_{max}}^2}{4} \cos(2\omega_r t) + B_{long} \theta_{p_{max}} \sin(\omega_p t) \quad (5)$$

$$B_L(t) = B_{vert} \theta_{p_{max}} \sin(\omega_p t) + B_{long} \left(1 - \frac{\theta_{p_{max}}^2}{4}\right) + B_{long} \frac{\theta_{p_{max}}^2}{4} \cos(2\omega_p t) \quad (6)$$



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Therefore, for small maximum roll angles ten separate problems are solved:

Problem Type	H _{ext} /Coil	Driver	Coefficient c_n
(1) Static	Horizontal	DC	$B_{horiz} \left(1 - \frac{\theta_{r_{max}}^2}{4}\right)$
(2) Static	Vertical	DC	$B_{vert} \left(1 - \frac{\theta_{r_{max}}^2}{4}\right)$
(3) Static	Longitudinal	DC	$B_{long} \left(1 - \frac{\theta_{p_{max}}^2}{4}\right)$
(4) AC SS	Horizontal	$\cos(2\omega_r t)$	$B_{horiz} \frac{\theta_{r_{max}}^2}{4}$
(5) AC SS	Vertical	$\sin(\omega_r t)$	$B_{vert} \theta_{r_{max}}$
(6) AC SS	Horizontal	$\sin(\omega_r t)$	$B_{horiz} \theta_{r_{max}}$
(7) AC SS	Vertical	$\cos(2\omega_r t)$	$B_{vert} \frac{\theta_{r_{max}}^2}{4}$
(8) AC SS	Longitudinal	$\sin(\omega_p t)$	$B_{long} \theta_{p_{max}}$
(9) AC SS	Longitudinal	$\cos(2\omega_p t)$	$B_{long} \frac{\theta_{p_{max}}^2}{4}$
(10) AC SS	Vertical	$\sin(\omega_p t)$	$B_{vert} \theta_{p_{max}}$

It is assumed that the individual problems are solved for unit values of the driving field; the actual fields are in the coefficients. Once the solutions to the ten problems are obtained, the total solution is the superposition of the real parts. E.g., the vertical field component at a point (x_p, y_p, z_p) at time, t is:

$$B_z(x_p, y_p, z_p; t) = \sum_{n=1}^3 c_n B_z^n(x_p, y_p, z_p; 0) + \sum_{n=4}^{10} c_n Re\{B_z^n(x_p, y_p, z_p; t)\} \quad (7)$$

where $B_z^n(x_p, y_p, z_p; t)$ is the field component from the nth problem at the point. Alternatively, this can be written as:

$$B_z(x_p, y_p, z_p; t) = \sum_{n=1}^3 c_n B_z^n(x_p, y_p, z_p; 0) + \sum_{n=4}^{10} c_n \left[Re\{B_z^n(x_p, y_p, z_p)\} \cos(\omega t) + Im\{B_z^n(x_p, y_p, z_p)\} \sin(\omega t) \right] \quad (8)$$

Similar expressions occur for the other components and variables such as current density, etc.

The easiest way to get signatures is to use a large solenoid to drive a uniform field. In the POST processor delete the coils, SET FIELD=INTEGRATE, and calculate the desired components at the desired points.

An example of a simple rolling box in both a horizontal and vertical field is shown below. An ELEKTRATR case is compared to the ELEKTRASS cases and the summation algorithm described above. Following the Figures is an extract from the Excel Workbook with the formulas for the fields shown.



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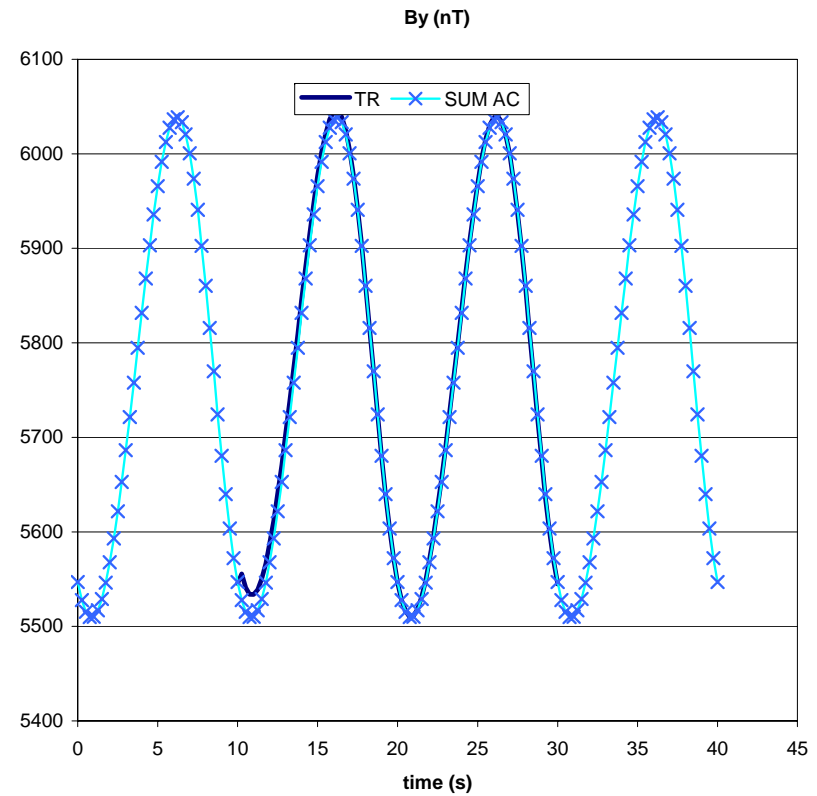
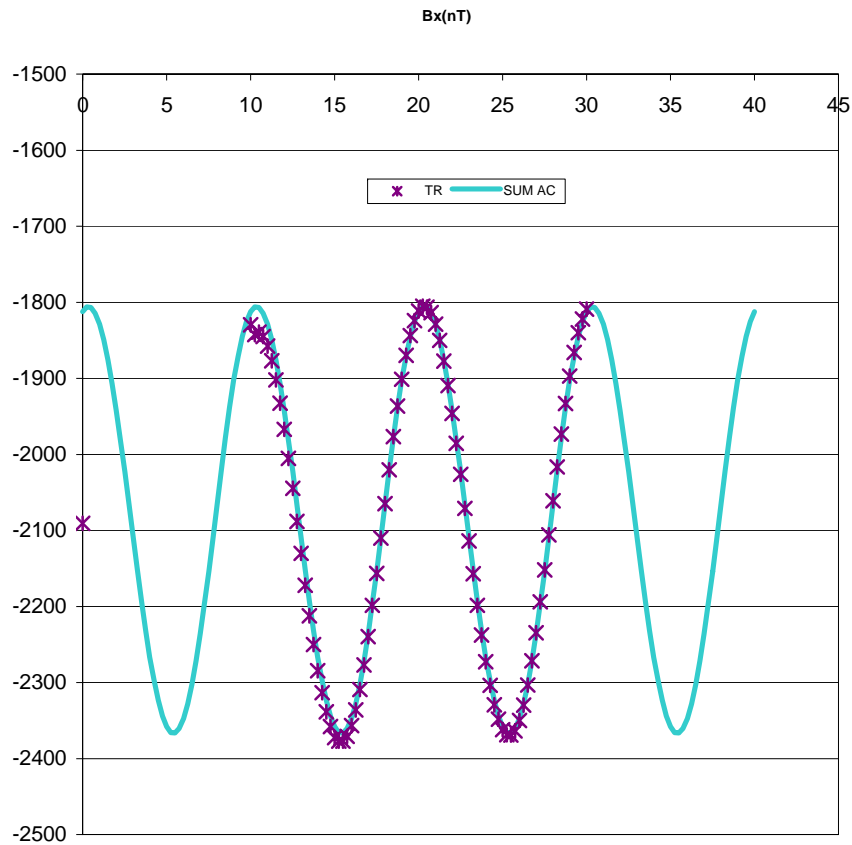


Figure 1 – Vertical and Horizontal Signature a “beam” depth below the simple box versus time for ELEKTRATR and ELEKTRASS (with summation)



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	A	B	C	D		F	G	H	I	J	K	L	M	N	
1	time(s)	Bx	By	Bz		1	13.9733	0.0000	-149.3431	0.0000	-0.0006	0.0000	0.0006	0.0000	
2	0.00	-1.81E+03	5.55E+03	1.46E-01		2	32.9372	0.0000	0.0005	0.0000	175.1437	0.0000	-0.0006	0.0000	
3	0.25	-1.81E+03	5.53E+03	1.34E-01		3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
4	0.50	-1.81E+03	5.52E+03	1.17E-01		4	0.0267	2.0000	61.5534	-71.1514	0.0083	0.0196	-0.0857	-0.0182	
5	0.75	-1.81E+03	5.51E+03	9.76E-02		5	2.8798	1.0000	94.7584	22.7915	0.0036	-0.0081	0.0426	-0.0326	
6	1.00	-1.83E+03	5.51E+03	7.48E-02		6	1.2217	1.0000	0.0054	-0.0090	-171.3999	-130.5285	0.0246	0.0214	
7	1.25	-1.85E+03	5.52E+03	4.98E-02		7	0.0628	2.0000	-0.0190	0.0267	-198.1613	145.1085	0.1094	0.0197	
8	1.50	-1.88E+03	5.53E+03	2.32E-02		8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
9	1.75	-1.91E+03	5.55E+03	-4.16E-03		9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
10	2.00	-1.94E+03	5.57E+03	-3.15E-02		10	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
11	2.25	-1.98E+03	5.59E+03	-5.82E-02			coeff	Freq	rbx	ibx	rby	iby	rbz	ibz	
12	2.50	-2.02E+03	5.62E+03	-8.34E-02											
13	2.75	-2.07E+03	5.65E+03	-1.06E-01		Time step	0.25		toffset	0.0					
14	3.00	-2.11E+03	5.69E+03	-1.27E-01		Hvert	33.0	41469	Roll Freq	0.1	0.628319				
15	3.25	-2.15E+03	5.72E+03	-1.44E-01		Hhoriz	14.0	17593	ThetaRmax	5.0	0.087266				
16	3.50	-2.19E+03	5.76E+03	-1.58E-01		Hlong	0.0	0	Ptich Freq	0.0	0.000000				
17	3.75	-2.23E+03	5.79E+03	-1.68E-01					ThetaPmax	0.0	0.000000				
18	4.00	-2.27E+03	5.83E+03	-1.74E-01											
19	4.25	-2.30E+03	5.87E+03	-1.76E-01		Bx=	\$G\$1*\$I\$1+\$G\$2*\$I\$2++\$G\$3*\$I\$3								
20	4.50	-2.32E+03	5.90E+03	-1.74E-01			'+\$G\$4*(\$I\$4*COS(\$H\$4*\$H\$14*\$A2)+\$J\$4*SIN(\$H\$4*\$H\$14*\$A2))								
21	4.75	-2.34E+03	5.94E+03	-1.68E-01			'+\$G\$5*(\$I\$5*COS(\$H\$5*\$H\$14*\$A2)+\$J\$5*SIN(\$H\$5*\$H\$14*\$A2))								
22	5.00	-2.36E+03	5.97E+03	-1.59E-01			'+\$G\$6*(\$I\$6*COS(\$H\$6*\$H\$14*\$A2)+\$J\$6*SIN(\$H\$6*\$H\$14*\$A2))								
23	5.25	-2.37E+03	5.99E+03	-1.47E-01			'+\$G\$7*(\$I\$7*COS(\$H\$7*\$H\$14*\$A2)+\$J\$7*SIN(\$H\$7*\$H\$14*\$A2))								
24	5.50	-2.37E+03	6.01E+03	-1.31E-01			'+\$G\$8*(\$I\$8*COS(\$H\$8*\$H\$14*\$A2)+\$J\$8*SIN(\$H\$5*\$H\$14*\$A2))								
25	5.75	-2.36E+03	6.03E+03	-1.13E-01			'+\$G\$9*(\$I\$9*COS(\$H\$9*\$H\$14*\$A2)+\$J\$9*SIN(\$H\$6*\$H\$14*\$A2))								
26	6.00	-2.35E+03	6.04E+03	-9.26E-02			'+\$G\$10*(\$I\$10*COS(\$H\$10*\$H\$14*\$A2)+\$J\$10*SIN(\$H\$7*\$H\$14*\$A2))								
27	6.25	-2.33E+03	6.04E+03	-7.03E-02											
28	6.50	-2.30E+03	6.03E+03	-4.66E-02		By=	Similar (replace I\$ with \$K\$ and J\$ with \$L\$)								
29	6.75	-2.27E+03	6.02E+03	-2.20E-02											
30	7.00	-2.24E+03	6.00E+03	3.01E-03		Bz=	Similar (replace I\$ with \$M\$ and J\$ with \$N\$)								