# Comparison Between Genetic and Particle Swarm Optimization Algorithms in Optimizing Ships' Degaussing Coil Currents

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***Abstract*** **─** This paper presents a comparison between two well-known evolutionary algorithms in optimization of the degaussing coils currents of a ship which are used to reduce the magnetic anomalies of the ferromagnetic hull of the ships induced by the Earth's magnetic field. To achieve this, first the magnetic anomalies of a simple model of a ship and the effect of each degaussing coil are simulated by using 3D finite element analysis (FEA) software. Then, both genetic algorithm and particle swarm optimization are used to find the best fitting coil currents which can reduce the anomalies of the ship. Using these algorithms is much simpler than optimizing this problem in FEA software in which a huge amount of numerical analyses are needed. This comparison will show which of these algorithms works better in this specific problem.

***Index Terms*** **─** Degaussing system, ferromagnetic material, genetic algorithm, magnetic anomaly, magnetization, particle swarm optimization.

## I. INTRODUCTION

When iron ships are exposed to the Earth's magnetic field, magnetic regions of the ferromagnetic iron are aligned in the direction of the external field. This process, which is called Magnetization, produces some magnetic anomalies in their environment, which are named as induced component. Besides, due to the magnetic history of the iron, another component of magnetization is generated which is called remnant magnetization. For ships, it is vital to reduce these anomalies as least as possible for safety against magnetic mines and torpedoes.

Determination of the remnant component needs some measurement data and is discussed in some references like [1]. It is almost impossible to calculate this component with software because the magnetic history of the ferromagnetic material is unknown and all works are done based on measurements. On the other hand, induced component can be simulated by software and there is no need for measurements. The common point of these two magnetization components is that the countermeasure methods against them are somehow similar. Degaussing and deperming both use some coils in order to produce the same anomalies of the ship but exactly in the reverse direction in order to reduce the total magnetic anomalies.

This paper will focus on the induced magnetization and optimization of the degaussing coil currents. First, the magnetic signature of a ship is analyzed with FEA software and then the effects of each degaussing coil are simulated considering the hull effect of the ship. The hull effect is some kind of shielding effect that causes some changes in the generated filed of each coil which comes from additional magnetization of the hull induced by the coil currents [2, 3].

Because the optimization of the degaussing currents with software is a three dimensional inverse problem, it will need a huge amount of numerical analyses which will be very time consuming. In [2-4] it is proposed to do these optimizations separately with taking the linearity of the system into account. In this case, instead of solving problem for a large volume, a measurement line in a specific depth beneath the ship is considered as a region of the solution and the aim of the optimization is the reduction of the total field on this line as least as possible. This method is so effective which can reduce the time of the optimizations in a considerable way.

Although this method is very effective, it can be improved by some changes in the optimization process. Each of references has optimized this problem with a different algorithm and it seems that a comparison among optimization algorithms is necessary. In this paper, this comparison will be done between two well-known genetic algorithm and particle swarm optimization methods. These algorithms are stochastic search methods and their results could be somehow fortuitous. In order to omit this effect, ten tests for each algorithm are done and the results are presented in average form. Finally, the best results of each algorithm are compared to identify which algorithm could be more effective in degaussing problem.

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## II. MAGNETIC SIGNATURE OF THE SHIP

Based on the directions of the ship and the Earth's magnetic field, three general magnetic signatures are introduced; induced longitudinal magnetization (ILM), induced vertical magnetization (IVM) and induced athwartship magnetization (IAM) [5, 6]. Any other arbitrary field can be expressed in the form of these three modes which are shown in Fig. 1. The dimensions of the ship are about 130×20×17 m with 3-4 cm thickness. The magnitude of the Earth's magnetic field is supposed to be 55000 nT and the relative permeability of the hull is assumed to be 80. Simulations of the magnetic signatures were done through FEA software by a computer with an Intel Core i7-2640M @ 2.8 GHz and the results are shown in Fig. 2. The fields are measured over a hypothetical line in the depth of 10 m exactly under the keel of the ship and with the length of 400 m. The results of the whole simulations have been obtained in the range of 0-400 m, but for increasing the resolution of the figures and clarifying the differences of their curves only the 200 m middle part of the measurement line is represented in the figures. The values in hidden parts (0-100 m and 300-400 m) in all figures are close to zero.

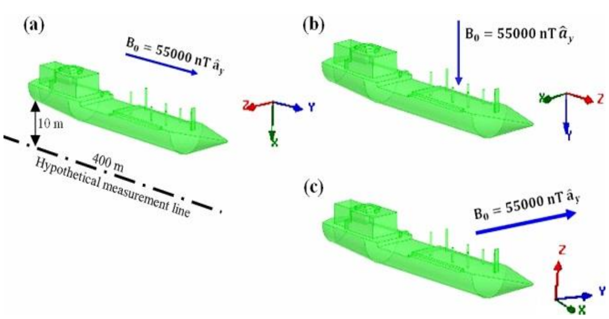



Fig. 1. Three general signatures: (a) ILM, (b) IVM, and (c) IAM.

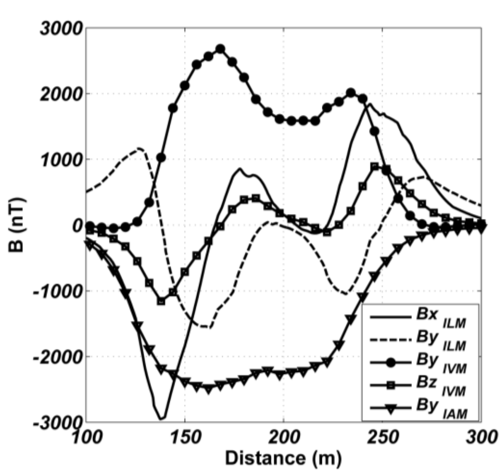



Fig. 2. Magnetic signature of the ship in three modes.

## III. DEGAUSSING SYSTEM

For cancelation of magnetic signature, ships are equipped with three types of coils which are named as L-coils, V-coils and A-coils. These coils are designed to cancel longitudinal, vertical and athwartship signatures of the ships, respectively [7]. The degaussing system which is used in this paper is shown in Fig. 3. In this system 20 L-coils with approximate dimension of 11×6 m, 20 V-coils with approximate dimension of 11×6 m and 10 A-coils with approximate dimension of 12×5 m are designed. In Fig. 3, it is obvious that some coils are smaller and the above-mentioned dimensions are related to the big ones.

For achieving the effects of each coil, simulations are done by exciting single coil with a reference current of 1 KA while other coils having no current. It took approximately 35 minute to obtain FEA solution for only one coil. In Fig. 4 the fields of A-coils are shown. The magnetic fields of these coils have no x or z component on the measurement line and it is due to the symmetry of these fields according to the assumed measurement line.

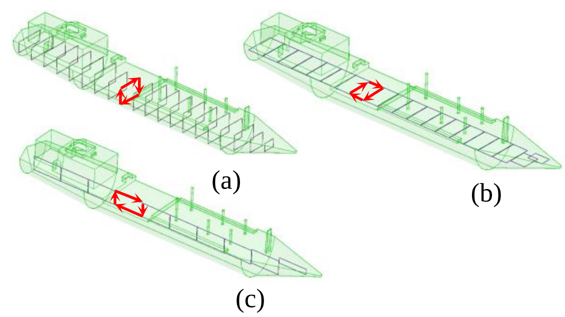



Fig. 3. Degaussing coils: (a) L-coils, (b) V-coils, and (c) A-coils.

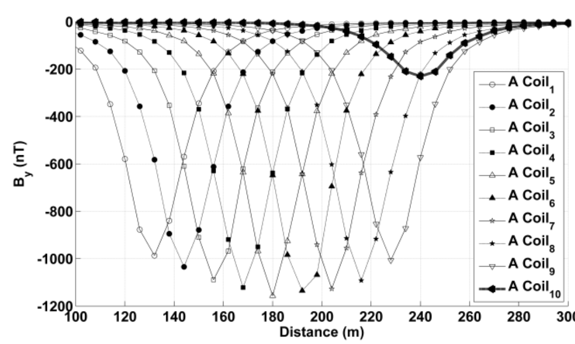



Fig. 4. Magnetic fields produced by A-coils.

The generated magnetic fields of L-coils and V-coils have two components (for L-coils: $B_x$ and $B_y$; and for V-coils: $B_y$ and $B_z$) which results in a total number of eighty curves for these forty coils. The results of these coils are somehow similar to Fig. 4, and to avoid repetition are not shown here.

## IV. OPTIMIZATION ALGORITHMS

### A. Particle swarm optimization

The PSO is inspired by the social behaviour of a flock of migrating birds trying to reach an unknown destination. In PSO, each solution is a 'bird' in the flock and is referred to as a 'particle' [8]. The strategy and exact formulation of this algorithm is explained in details in [9, 10]. Here a brief review on its process is presented. In this algorithm first a random population of particles is generated and the cost value for each particle is calculated. Then the best cost value is saved as global best answer and the cost value of each particle is saved as personal best answer. After that, particles start to move in search space and the position and the velocity of each particle is determined based on the global and personal best values in every iteration. The algorithm continues until the global cost value reaches to the desired limit or until last iteration. The general formulation of PSO is represented as follow [8]:

$$\begin{cases} X_i = (x_{i1}, x_{i2}, \dots, x_{is}) \; current\ position\ of particle\ i \\ P_i = (p_{i1}, p_{i2}, \dots, p_{is}) \quad best\ pervious\ position \\ V_i = (v_{i1}, v_{i2}, \dots, v_{is}) \quad flying\ velocity \end{cases}$$

$$New\ V_i = w \times current\ V_i + c_1 \times rand(.) \times (P_i - X_i) + c_2 \times rand(.) \times (P_g - X_i), \quad (1)$$

$$New\ X_i = X_i + New\ V_i, \quad (2)$$

$$-V_{max} \le V_i \le V_{max}. \quad (3)$$

In these equations S is the number of variables, w is an inertia weight, $c_1$ and $c_2$ are two positive constants named learning factors and $V_{max}$ is an upper limit on the maximum change of the velocity of a particle.

In Table 1 the parameters of PSO which are used in this paper are shown. In compensation of ILM and IVM signatures, each signature has two components (as shown in Fig. 2; for ILM: $B_x$ and $B_y$ and for IVM: $B_y$ and $B_z$) and the optimizations are done on both components simultaneously, therefore, in these modes bigger iteration number is chosen.

Table 1: Parameters of the particle swarm optimization

| Name | Value |
|---|---|
| Population size | 200 |
| Iteration | 500 for ILM and IVM<br>200 for IAM |
| $c_1$, $c_2$ | 2 |
| $V_{max}$ | 2 |
| Initial range | [−2,0] for IAM and IVM<br>[0,2] for ILM |

### B. Genetic algorithm

Genetic algorithm is inspired by biological systems' improved fitness through evolution. A solution to a given problem is represented in the form of a string, called 'chromosome', consisting of a set of elements, called 'genes', that hold a set of values for the optimization variables [8]. This algorithm works based on a random population of solutions (chromosomes) and then the fitness value (cost) of each chromosome is evaluated in cost function. In the next iterations chromosomes exchange information with each other in the form of crossover and mutation and offspring chromosomes are generated. After that, the best chromosomes are saved for the next iterations and the weak members of the population are omitted. More explanation about GA could be found in [11, 12]. The specified parameters of GA which are used in optimization of the degaussing coil currents are shown in Table 2.

Table 2: Parameters of the genetic algorithm

| Name | Value |
|---|---|
| Population size | 200 |
| Iteration | 500 for ILM and IVM<br>200 for IAM |
| Crossover rate | 75% |
| Mutation rate | 5% |
| Initial range | [−2,0] for IAM and IVM<br>[0,2] for ILM |

## V. IMPLEMENTATION OF THE OPTIMIZATIONS

The magnetic signatures of the ship and the generated fields of the degaussing coils are achieved in section two and section three, respectively. Now the optimizations could be done by determining cost function as follow:

$$F = \min\left(\max\left(\sum_{i=1}^{n}\sum_{j=1}^{p}\left|B_j^{xship} - c_i B_j^{x,Li}\right|, \sum_{i=1}^{n}\sum_{j=1}^{p}\left|B_j^{yship} - c_i B_j^{y,Li}\right|, \sum_{i=1}^{n}\sum_{j=1}^{p}\left|B_j^{zship} - c_i B_j^{z,Li}\right|\right)\right), \quad (4)$$

where $i = 1,2, \dots, n$ are the number of coil, $j = 1,2, \dots, p$ are the number of measurement points (sensors), $B_j^{xship}$ is the x component of the signature of the ship and $B_j^{x,Li}$ is the x component of the generated filed of the i-th coil in the j-th sensor. It should be noted that the $c_i = c_1, c_2, \dots, c_n$ are the coefficients which are the answers of the optimization. Finally these coefficients will be multiplied by the reference current (or mmf) to find the value of the coils currents.

Due to the fortuitous natures of the GA and PSO, comparing these algorithms in a specific problem through only one test could not be correct and it is necessary to compare the performance of theses algorithms during multiple tests. The only parameter that varies in these tests is the starting point of the algorithms. Both algorithms use a random function to choose the starting point (initial answer of the problem) but in some cases one of the algorithms starts with an answer very close to the optimum answer. In situations like this, the algorithm which has started with a worse point may have a better performance than the other algorithm but this better performance is not clear when comparing the final answers. Therefore, ten tests for each algorithm have been done for each type of signature which leads to the total number of sixty tests. In the next parts, the best result of each algorithm for ILM, IVM and IAM will be compared and after that a final comparison between average performances will be done.

**A. Induced longitudinal magnetization**

As mentioned before, the ILM signature of the model ship (according to the coordinate system and the position of the measurement line) has two components of x and y which are shown in Fig. 2. Just like the signature of the ship, L-coils generate magnetic field in these two directions and they could compensate the signature of the ship in this case. The calculated current value of each L-coil is depicted in Fig. 5 and the best results from ten tests are shown in Fig. 6. It should be noted that the signature of the ship in Fig. 6 is reversed. The exact value of remnant field after degaussing, its percentage and the optimization time are shown in Table 3.

Although the running time of GA is 3.5% more than PSO's, the best result of GA is 3.75% and 7.16% more accurate in x and y directions respectively in comparison with the best result of PSO. Finally, the cost value in each iteration is shown in Fig. 7. It is obvious that after first iterations, GA has lower cost in comparison with PSO for the same number of iterations.

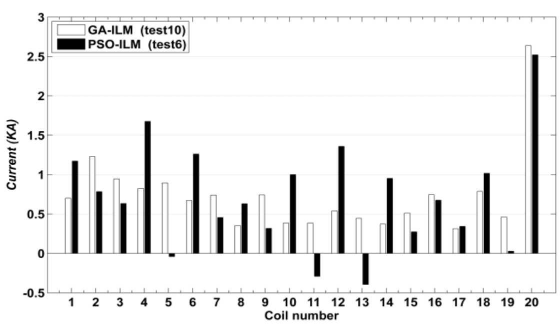
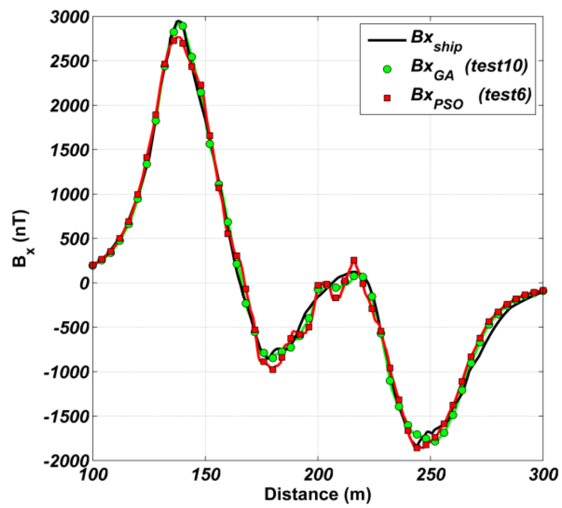
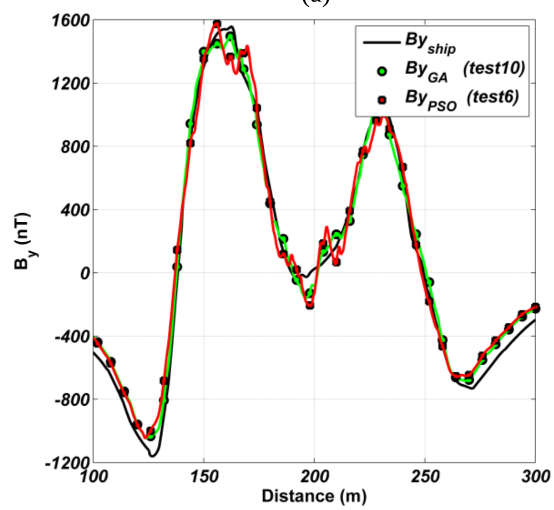



Fig. 5. Current values of the L-coils.




(a)




(b)

Fig. 6. Degaussing result for L-coils in comparison with the ILM signature of the ship (reversed): (a) Bx and (b) By.

Table 3: Optimization result of the ILM signature

| Name<br>(Best Results) | ILM-GA<br>(Test 10) | ILM-PSO<br>(Test 6) |
|---|---|---|
| Best cost -x direction (nT) | 140.30 | 250.79 |
| Best cost -y direction (nT) | 139.39 | 251.07 |
| Remnant field after degaussing -x direction (%) | 4.75 | 8.50 |
| Remnant field after degaussing -y direction (%) | 8.94 | 16.10 |
| Run time(s) | 144.9 | 140.0 |

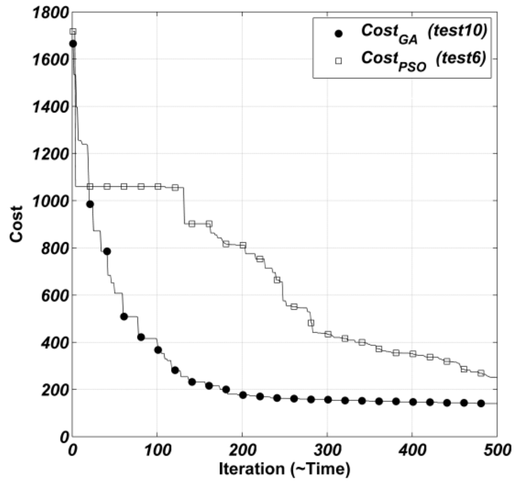
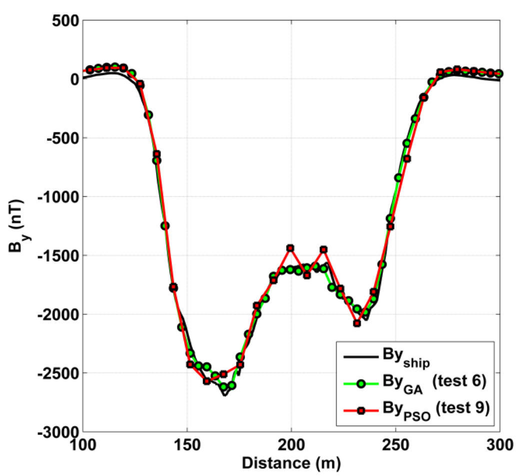



Fig. 7. Comparison of the convergence speed in ILM.

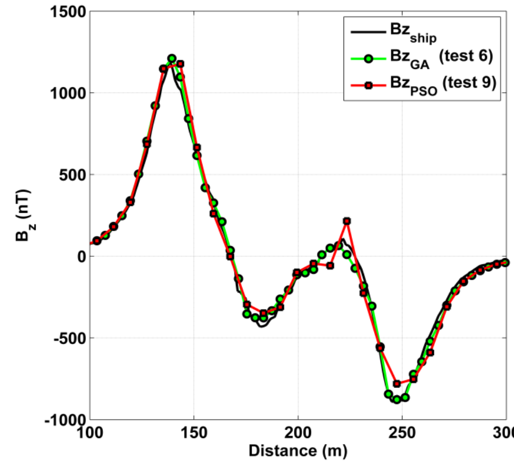
### B. Induced vertical magnetization

The IVM signature of the model ship has two components of y and z which are shown in Fig. 2. Just like the signature of the ship, V-coils generate magnetic field in these two directions and they could compensate the signature of the ship in IVM mode. The best results from ten tests are shown in Fig. 8 and the current value of each V-coil is depicted in Fig. 9.

Remnant field after degaussing, its percentage and the optimization time are presented in Table 4. Just like the ILM mode, although the running time of GA is 7.76% more than PSO's, the best result of GA is 2.56% and 5.83% more accurate in y and z directions respectively in comparison with the best result of PSO. Finally, the cost value in each iteration is shown in Fig. 10. It is obvious that after first iterations, the GA has lower cost in compared with PSO for the same number of iterations.




(a)




(b)

Fig. 8. Degaussing result for V-coils in comparison with the IVM signature of the ship (reversed): (a) By and (b) Bz.

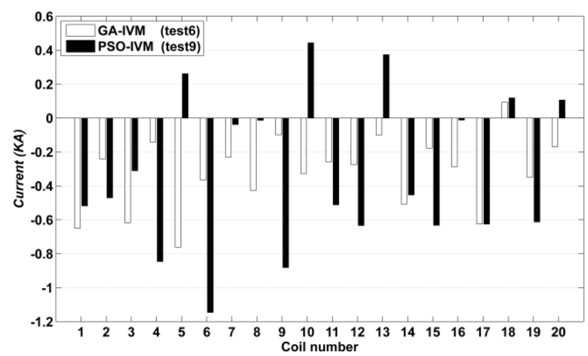



Fig. 9. Current values of the V-coils.

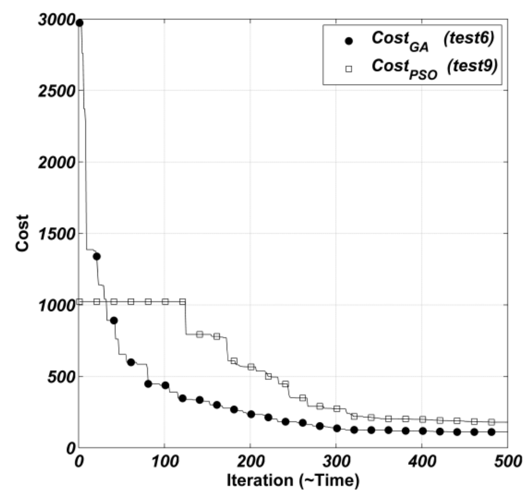



Fig. 10. Comparison of the convergence speed in IVM.

Table 4: Optimization result of the IVM signature

| Name (Best Results) | IVM-GA (Test 6) | IVM-PSO (Test 9) |
|---|---|---|
| Best cost -y direction (nT) | 110.06 | 178.90 |
| Best cost -z direction (nT) | 109.43 | 178.95 |
| Remnant field after degaussing -y direction (%) | 4.08 | 6.64 |
| Remnant field after degaussing -z direction (%) | 9.18 | 15.01 |
| Run time(s) | 145.8 | 135.3 |

### C. Induced athwartical magnetization

The IAM signature has only one component, y, which is shown in Fig. 2. Just like the signature of the ship, A-coils generate magnetic field in this direction and they could compensate the signature of the ship. The best results from ten tests are shown in Fig. 11 and the current value of each A-coil is depicted in Fig. 12. The exact value of remnant field after degaussing, its percentage and the optimization time are shown in Table 5. Finally, for investigating the convergence speed of algorithms, the cost value in each iteration is shown in Fig. 13. The running time of GA is 8.47% more than the PSO's but the result of PSO is 0.05% more accurate in comparison with the best result of GA.

It is obvious that after first iterations, GA has lower cost in comparison with PSO for the same number of iterations. Although the final result of PSO in IAM mode is more accurate in comparison with GA (only 0.05%), Fig. 13 shows the better performance of GA. The better result of PSO in this specific case is a good sample of the fortuitous natures of these algorithms and reveals that comparing the performance of these algorithms through only one simple test is not logical.

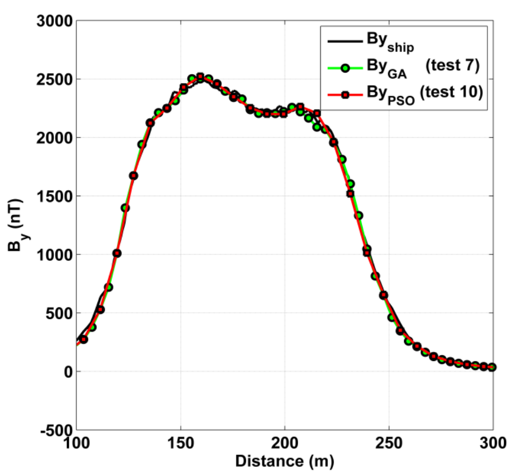



Fig. 11. Degaussing result for A-coils in comparison with the IAM signature of the ship (reversed).

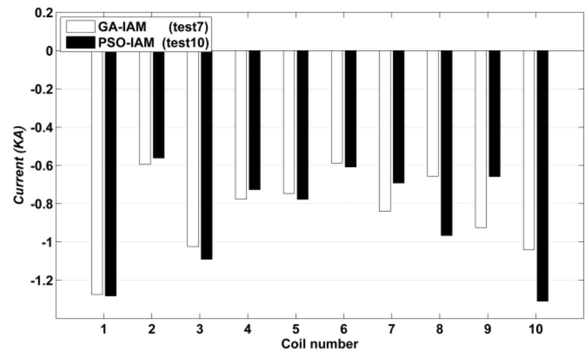



Fig. 12. Current values of the A-coils.

Table 5: Optimization result of the IAM signature

| Name (Best Results) | IAM-GA (Test 7) | IAM-PSO (Test 10) |
|---|---|---|
| Best cost -y direction (nT) | 97.93 | 96.66 |
| Remnant field after degaussing -y direction (%) | 3.87 | 3.82 |
| Run time(s) | 25.6 | 23.6 |

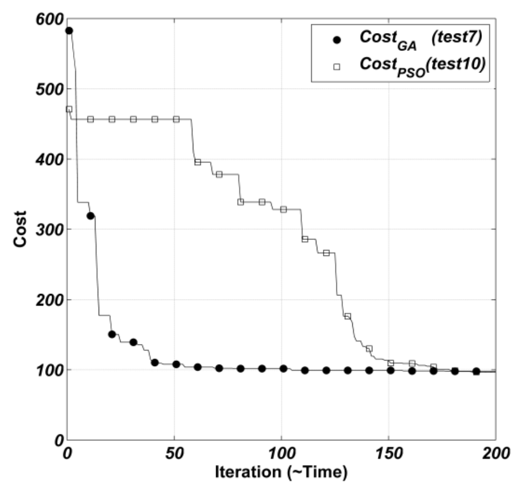



Fig. 13. Comparison of the convergence speed in IAM.

In Fig. 14 the results of the simulation of the degaussed ship are depicted. In this figure, the signature of the ship before and after degaussing process is compared for both PSO and GA optimizations. All coils are excited with the values of the electric currents represented in Fig. 9. To avoid the repetition of the figures only the results of IVM mode is represented. The maximum remnant fields after degaussing in PSO for y and z components are 252.3 and 174.4 nT respectively. By comparing these values with the ones reported in Table 4 (178.9 for y and 178.95 for z), it is revealed that the final results have 2.73% and 0.38% error for y and z components respectively (the difference between results are normalized based on the maximum values of the signatures that are 2688 nT and 1189 nT for y and z components respectively). These errors for GA optimizations are about 0.27% and 1.87%. The errors are small and tolerable, but the important point here is that these errors have two main sources. The mutual inductances between coils and the approximations which are used in any numerical simulations are the important factors that could easily affect the final results. Typically the distance between two adjacent coils is long enough to decrease their mutual inductance, and as a result in almost all references the mutual inductance is assumed as a negligible parameter.

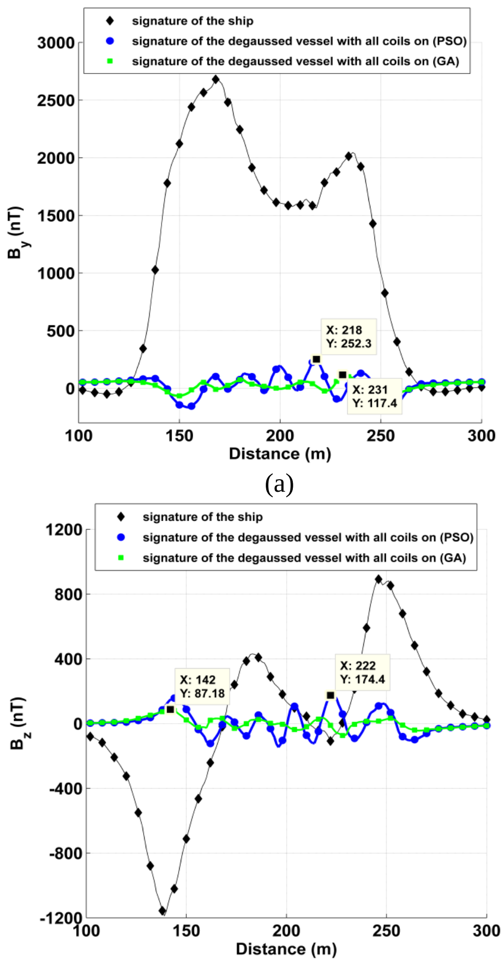



Fig. 14. Simulation of the degaussed ship in the IVM mode (V-coils are excited with the values of the electric currents represented in Fig. 9): (a) By and (b) Bz.

### D. Average results

Table 6 shows the average results of ten tests for all optimizations which are done for three ILM, IVM and IAM signatures. The average results reveal that the GA has better performance in comparison with PSO. However, it has more running time. This means that by tolerating a little bit increase in running time (in order of few seconds) the final result could be improved. Since the running time of the optimizations is not so long, it seems rational to use GA instead of PSO. It should be noted that both of these algorithms have been improved since their first development and the algorithms which are used in this paper are the base form of the optimization techniques.

Table 6: Average results of the optimizations

| Average Results | Cost in 1st Direction (nT) | Cost in 2nd Direction (nT) | Remnant Field in 1st Direction (%) | Remnant Field in 2nd Direction (%) | Run Time (s) |
|---|---|---|---|---|---|
| ILM-GA | 184.33 | 183.82 | 6.24 | 11.79 | 144.33 |
| ILM-PSO | 268.88 | 268.48 | 9.72 | 18.37 | 139.44 |
| IVM-GA | 175.65 | 175.79 | 14.73 | 6.52 | 147.61 |
| IVM-PSO | 252.73 | 253.02 | 21.19 | 9.39 | 136.5 |
| IAM-GA | 103.76 | - | 4.10 | - | 25.6 |
| IAM-PSO | 126.67 | - | 5.00 | - | 23.4 |

## VI. CONCLUSION

In this paper a comparison between genetic algorithm and particle swarm optimization in optimization of the degaussing currents is done. PSO has a reputation of being fast and easy to apply, but it is important to study the performance of these algorithms in this specific problem. In the case of the degaussing system, it seems that using GA is more beneficial in comparison with PSO. The main reason for this difference is that PSO could be easily trapped in local minimums. In PSO, the movement of the particles is strongly related to their local and global best positions. As a result if the algorithm finds a local minimum in the search space, the particles will move toward this point which will result a trap condition. This condition for GA is less possible. In GA due to the nature of crossover and mutation, it is always possible for the algorithm to find a solution away from the local answers. On the other hand, GA takes more time to run but considering the running time, this difference will be in the order of few seconds.

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