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A BOUNDARY ELEMENT PACKAGE CONTAINING APPROXIMATE SOLVERS FOR TREATING HIGH FREQUENCY ACOUSTIC SCATTERING

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Abstract

The target strength of objects submerged in water, located on the sea bottom or partially buried in the sediment can be calculated by means of a boundary element solver.

For this reason, a boundary element code with suitable pre-/postprocessor and parallel working solvers is developed. The scattering objects within the transition range between fluid and sediment can be modeled by the preprocessor. It can manage large and complex meshes (more than 100,000 elements) and is able to import mesh-files in different standard formats (e. g. NASTRAN-, ANSYS- or CDB-format) or to generate meshes with closed surfaces. Combined with material parameters, this information is used as a database for the following high frequency scattering calculations.

In the high frequency range, the computing time can be reduced drastically by using approximations instead of solving the complete system of BEM equations.

For this reason, a so-called plane wave approximation (PWA) has been implemented in the BEM-package for evaluating the scattered sound pressure. As an alternative high-frequency approximation the Kirchhoff approach, in order to compare and validate the results of both high frequency approximations, is also used.

The theory of these and additional high frequency approximations for scattering problems based on boundary integral equations is presented in another paper written by the authors [1].

Results will be given for the scattering of plane waves from cylindrical shells located in the free space up to 100 kHz.

1. INTRODUCTION

One main purpose in mine hunting is the detection and classification of sea mines placed on the seabed or partially buried in the sediment, especially in shallow water and port entrances. Numerical simulation gives a significant assistance and guideline for this task.

Existing studies are based mainly on time-domain formulations. Hence, numerical methods for the frequency-domain should be developed for supplementary support.

We are developing an application framework including parallel working equation solvers for the calculation of acoustic fluid-structure problems in the frequency-domain.

An existing FORTRAN Code (BEMLAP) based on [2] for the numerical solution of boundary element calculations using fluid-structure-interaction has to be analyzed with regard to structure sizes, performance and parallel execution. The code will be transformed in object-oriented C++-code and will be integrated in the calculation module.

Additionally the use and integration of alternative (i.e. iterative) or external solvers will be implemented and tested.

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2. APPLICATION FRAMEWORK

The application framework consists of three modules which will be described below.

2.1 Preprocessor

The preprocessor (with real-time 3D visualization as shown in Fig. 1, currently based on OpenGL) is used to define the geometric description of objects, the surrounding structures (fluid, ground), their material properties and the calculation parameters, including different sound sources.

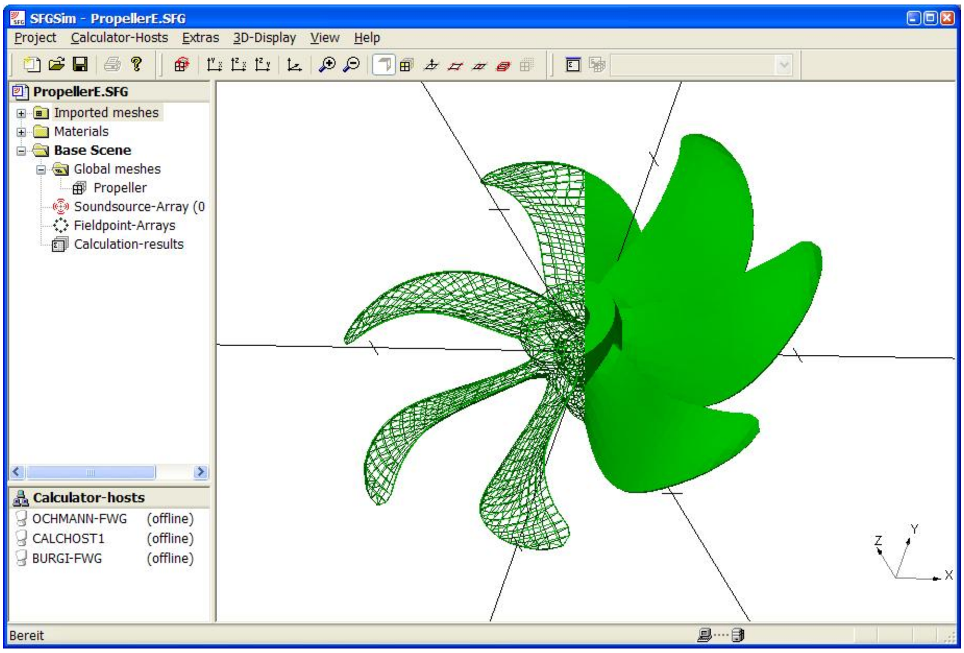

Fig. 1: Screenshot of the pre-/postprocessor with a complex mesh sample

The preprocessor currently includes the following features and options:

- Complete object-oriented design, intended to manage large and complex scenes (> 100,000 elements)
- Supports the import and export of 3D-structures (currently NASTRAN-, ANSYS- and CDB-format) including options to scale, translate and rotate
- Integrated mesh-generator for rippled fluid-ground-surfaces and sample structures
- Integrated mesh-combination algorithm for the generation of bonding geometric descriptions for fluid, ground and object meshes
- Supports the definition of material and acoustic properties for each structure in the scene and the “surrounding space”
- Supports the use of different types of sound sources
- Enabled to control external computers (so-called calculator-hosts) for the calculations using a TCP/IP-based interprocess-communication
- Standalone Microsoft Windows Application using Visual C++ .NET

In Fig. 2 an example of a generated scene including three objects and a fluid-ground surface after combining the meshes is shown.

The fluid structure and the third object are hidden (only the resulting cavity in the ground structure is visible).

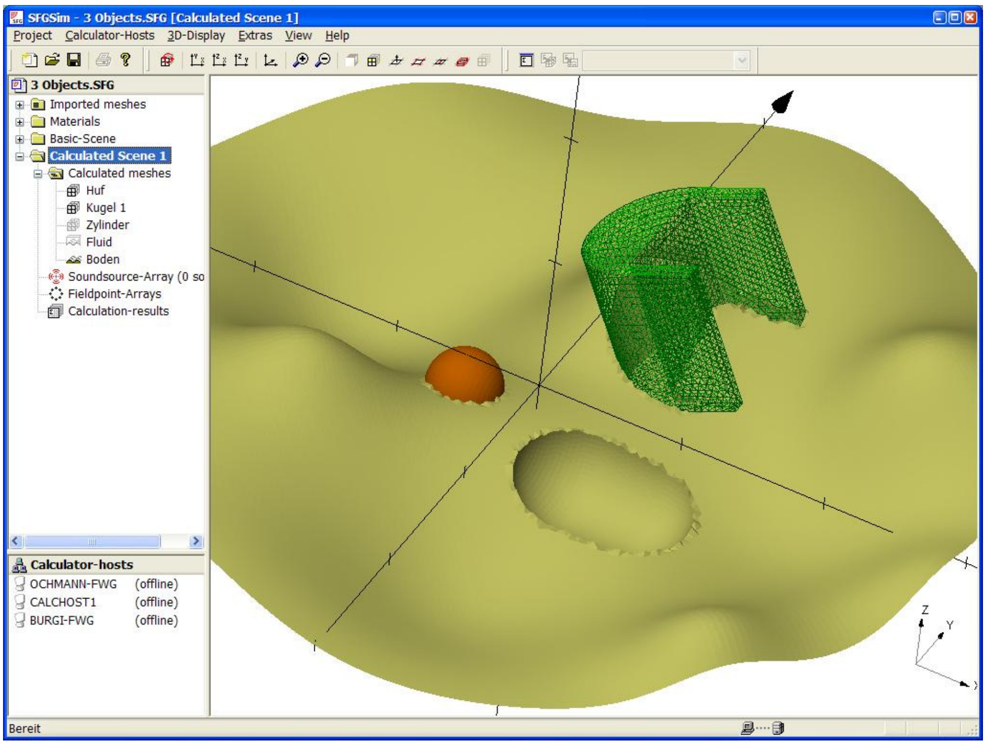

Fig. 2: Screenshot of a generated scene with three objects

2.2 Calculator

The calculation module is responsible for the real calculation processes and will be optimized for large data arrays and performance. For portability reasons, the code will be implemented mostly independent of the underlying operating system (Win32/64, LINUX).

The calculation module currently includes the following features and options:

- Implemented as a console application that can be executed standalone or as a system service under MS Windows (>= 2000) or LINUX (Kernel-Vs. >= 2.6)
- Code-sharing between all modules reduces development time and code complexity
- Using fixed structures and pointers during the calculation process enhances performance and reduces time-consuming memory reallocations
- Enable to run multiple calculation-tasks in separate threads (depending on the available hardware resources). In general every available and reachable PC-system may be used as a calculator-host
- The files used by the calculation-module can be easily installed and updated by the pre-processor using an integrated remote control option
- Integration and re-use of existing solver codes and external solvers is intended
- First implementations of solvers based on PWA (plane wave approximation) and Kirchhoff approach

2.3 Postprocessor

The postprocessor module which is used to display, export and print result data is integrated within the preprocessor, so both modules share the user interface and visualization properties. It currently includes the following features and options:

- Polls the status and the results from the calculator-hosts, assigns them to the appropriate projects and stores them locally
- Using unique IDs (generated by the pre-processor) for projects, scenes, meshes and calculations prevents from mixing different scene and result data
- Supports multiple types of result data (scalar, vectors, tensors, viewpoints) and assignments (element data for constant elements, node data for linear or quadratic elements etc.)
- Supports different types of data views and exports (2D-plots, 3D-visualisation using level-perspective or spatial projection, listings)
- Enable to import and visualize external calculated result data

3. METHODS AND RESULTS

Several high frequency approximations are well known in literature. In this paper, the plane wave approximation (PWA) and the so-called Kirchhoff approach is used. The theory of both approximations is presented and compared with respect to the scattering problem in full detail in the accompanying paper [1].

The solver was tested using a rigid sample structure (cylindrical object, length 2 m, diameter 0.5 m, one round cap, triangular elements) located in water (free space) as shown in Fig. 2 where a plane wave hits the scattering object under different angles of incidence (here at 70°).

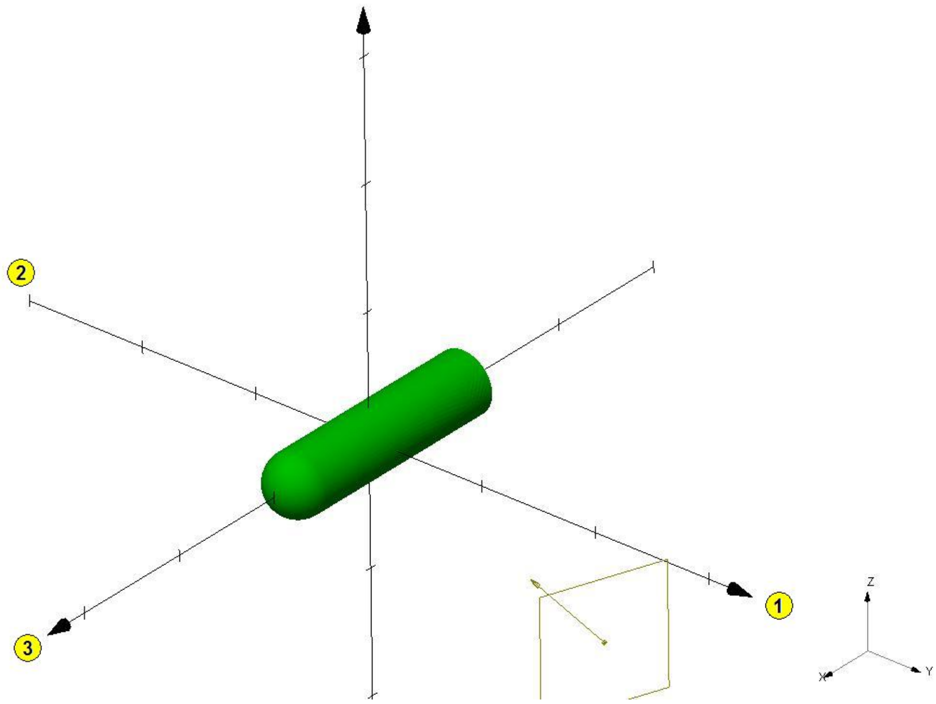

Fig. 2: Cylindrical scattering object with incident plane wave at 70°

Calculations have been made for two test cases and the results have been compared. The target strength is calculated based on the incident and the scattered pressure by

$$TS = 20\lg\left(r \cdot \frac{p_{scat}}{p_{inc}}\right), \tag{1}$$

whereas r is the distance between the center of the scattering object (used distance r=100 m) and the receiving field point, p_{scat} is the amplitude of the scattered pressure, and p_{inc} is the amplitude of the incident pressure.

The red curves in the following figures were calculated using the plane wave approximation (PWA); the green curves are based on results using the Kirchhoff approach (KIA).

3.1 Test case A: low and middle frequency range

In this case the target strength for a frequency sweep from 100 Hz to 10 kHz, using the described test structure with about 11,000 elements, has been calculated.

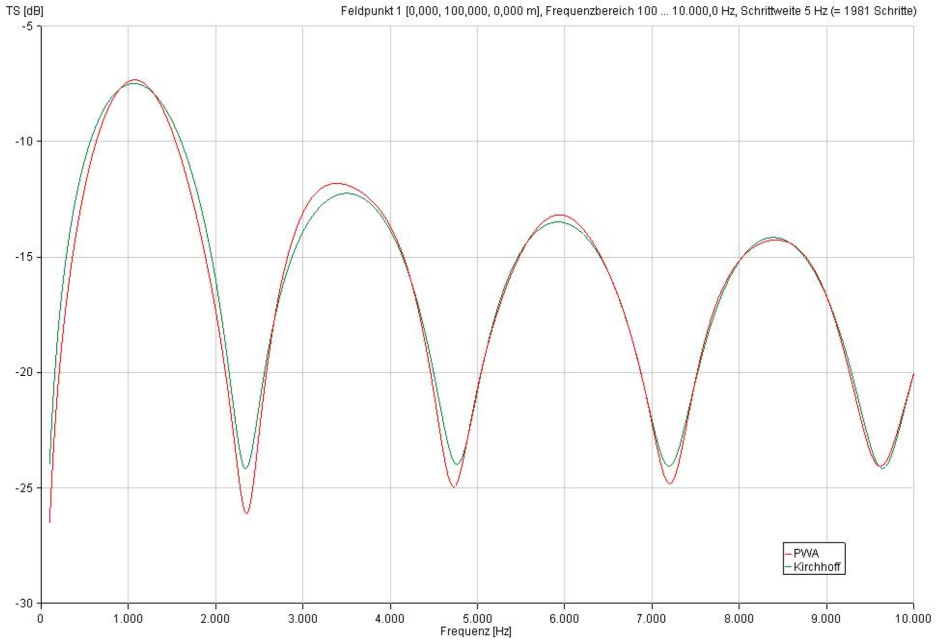

Fig. 3a, Target strength in dB at field point 1, red curve: PWA, green curve: Kirchhoff

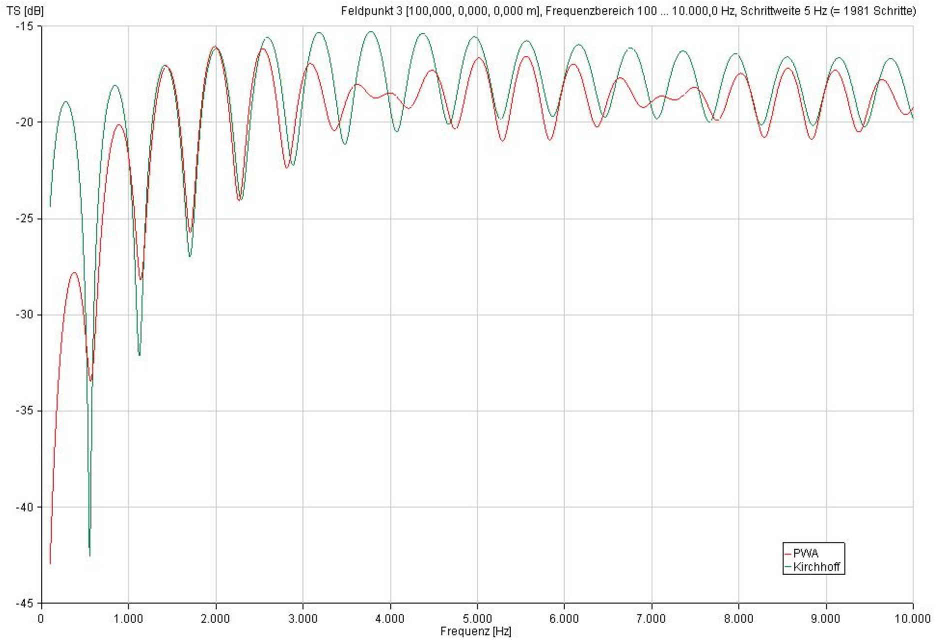

Fig. 3b, Target strength in dB at field point 3, red curve: PWA, green curve: Kirchhoff

A good accordance is achieved (Fig. 3a and 3b). The differences in Fig. 3b may result from the fact that the Kirchhoff solution only takes into account the “illuminated” parts of the structure [1]. The time required for this calculation using the PWA solution was 45 s for 1981 frequencies at 5 field points on a Core 2 Duo CPU with 2.4 GHz and 2 GB RAM.

3.2 Test case B: high frequency range

The target strength for a high frequency of 100 kHz within the three main planes, using the described test structure with about 1,500,000 elements, has been calculated in this test case.

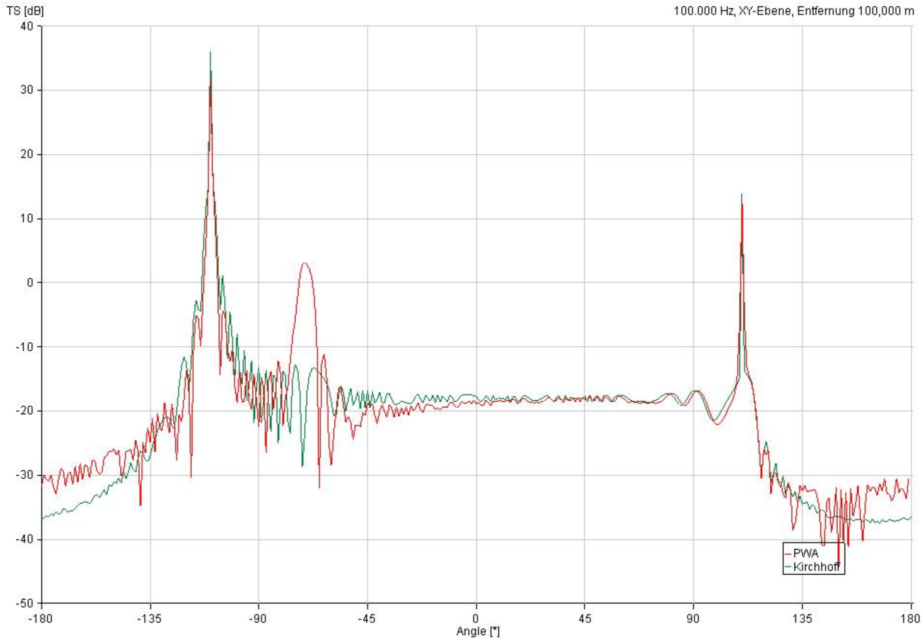

Fig. 4a, Target strength in dB, horizontal plane (XY), red curve: PWA, green curve: Kirchhoff

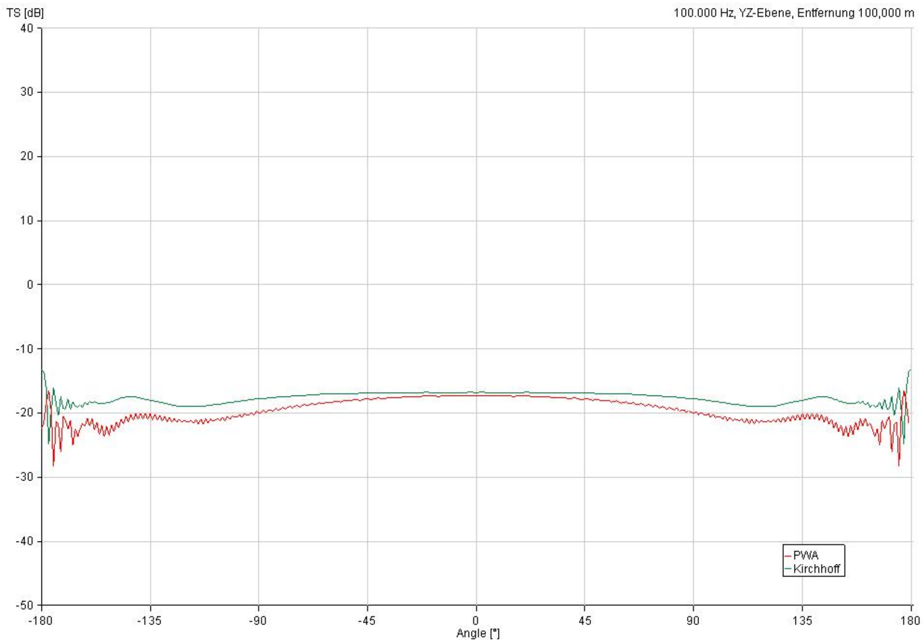

Fig. 4b, Target strength in dB, vertical plane (YZ), red curve: PWA, green curve: Kirchhoff

Here, one also obtains respectable similar results of the two methods. The time required for this calculation using the PWA solution was 520 s at 1,080 field points (3 planes, 360°, 1° stepping) on a Core 2 Duo CPU with 2.4 GHz and 2 GB RAM.

The postprocessor can also visualize the resulting target strength data from Fig. 4a in the form of a polar-plot as shown in Fig. 5.

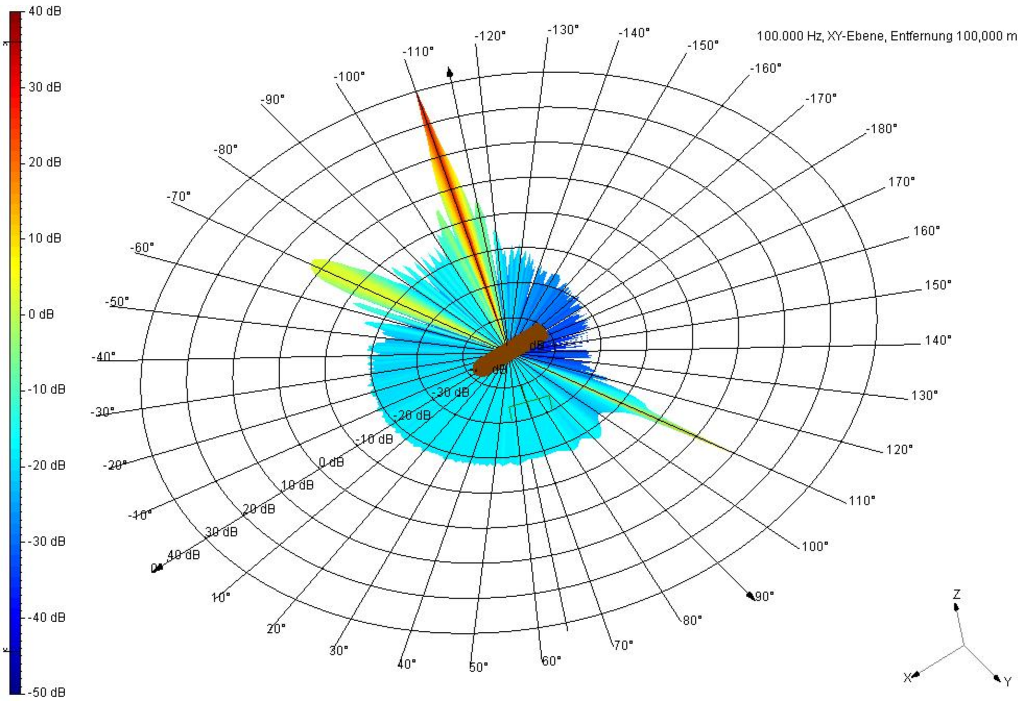

Fig. 5: Target strength at 100 kHz in the horizontal plane.

It can be seen that the sharp main lobe behind the scattering object is pointing into the direction of the incident plane wave.

4. SUMMARY

The pre-/postprocessor is used for creating complex scenes including the definition of material parameters, calculation options and sound sources. This data makes the base for the calculator module which offers parallel calculations on multiple systems.

High frequency solvers based on the PWA and the Kirchhoff approach leads to very similar results. In the near future, a complete boundary element method will be implemented including iterative solvers [3, 4] and fluid-structure-interaction [2, 5].

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