ADLS102 - Oscillator fluidelastic meridian

Abstract:

The purpose is to calculate the displacement of the piston of a “oscillator meridian fluid-elastic”.
It is about a piston-spring coupled with a fluid contained in a channel with rigid and fixed walls; the channel is crossed by one wave of depressurization.

One considers the plane problem of this meridian model. This two-dimensional problem is brought back to a monodimensional problem by considering by approximation that the rates of transverse flow induced by the motion of the piston are transmitted instantaneously out of axial velocities.

Only one modelization is used. The computation modes is in formulation $\boldsymbol{u}, p, \phi$.
One thus uses elements 2D; these elements are based on meshes QUAD4 for the fluid and the piston, on meshes SEG2 for the interface between fluid and piston to take into account the fluid interaction structure (PHENOMENE= `MECANIQUE', MODELISATION=' 2D_FLUI_STRU').

The boundary conditions of nonreturn of the wave are carried out by modelling a piston damper at each end; the excitation is carried out by applying a depression to the piston of entry.

The fluid which one considers is water (hot), the model schematizing the interaction fluid-structure in annular space between tank and envelope of heart during a fast depressurization.

An exact analytical solution exists. Its comparison with the results produced by *Code_Aster* makes it possible to validate the taking into account of the fluid coupling structure in 2D.

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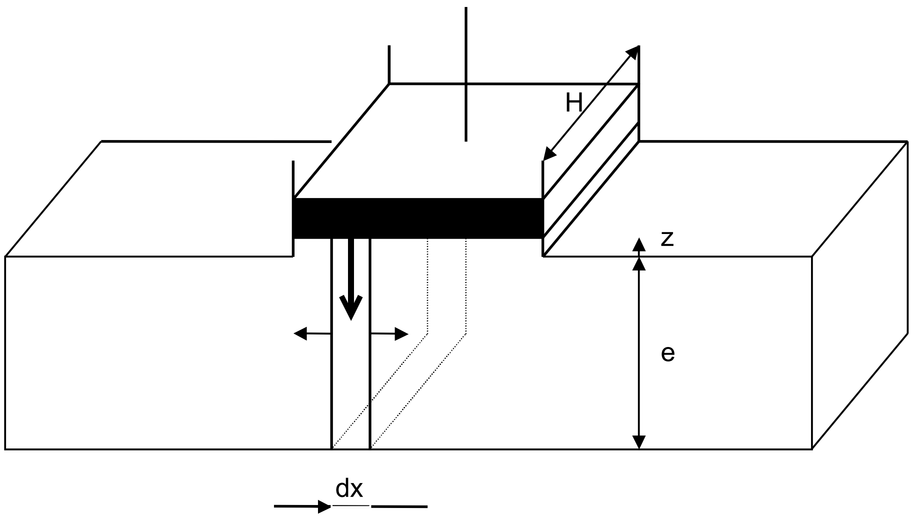
1 Problem of reference

1.1 Geometry

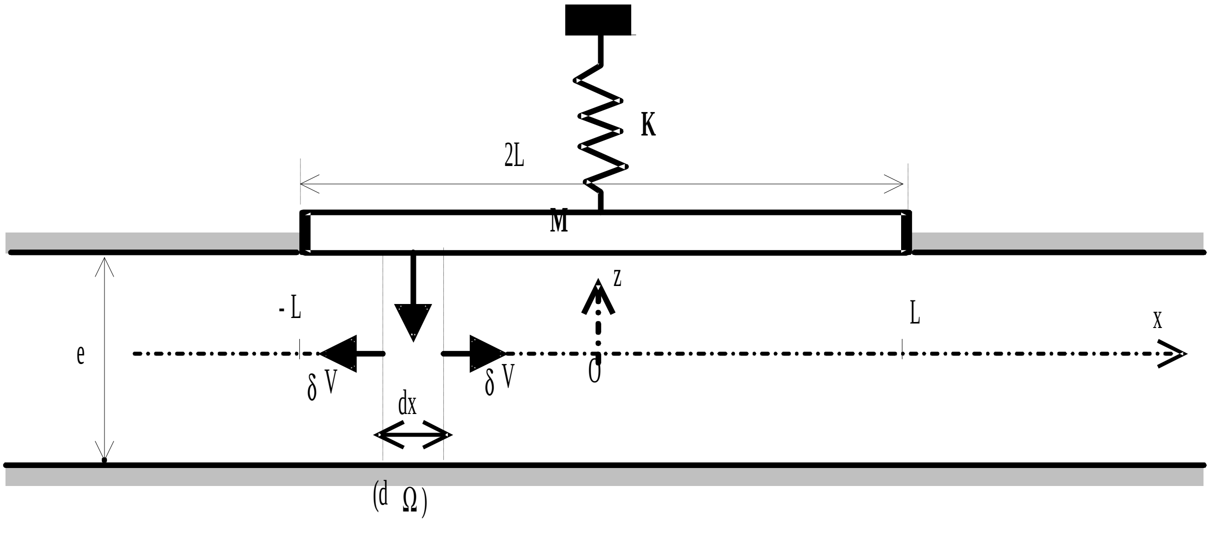
One describes below the model meridian oscillator fluidelastic schematizing the fluid interaction - structure in annular space tank-envelope of heart.
The meridian elastic fluid oscillator is a model of annular space tank-envelope of heart of engine; it consists of an oscillator (piston side-spring appearing a mobile wall) coupled with a compressible fluid contained in a channel with rigid and fixed walls.
The channel is crossed by one wave of depressurization.
The figure [Figure 1.1-a] below illustrates the model described.



Appear 1.1-a: Total diagram of the oscillator meridian fluid-elastic

the channel is of section rectangular of dimensions $e \times H$ the rigid side piston moves according to z perpendicular to a wall.
One wave of depressurization arrives by the left; while moving towards the line (without possibility of return) this wave aspires the piston which, by its resulting displacement, generates waves being propagated towards the ends of the conduit, supposed infinitely long so that there is no reflection.

One conceives a two-dimensional modelization of this system, represented with figure [Figure 1.1-b] Ci - below:



Appear 1.1-b: Theoretical two-dimensional mechanical representation

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Its geometrical characteristics are the following ones:

length piston of wall	$2L=5,0\,m$
height of fluid	$e=0,5\,m$
width of fluid	$H=1,0\,m$
fluid Properties section	$S=e.H$

1.2 of the materials

the physical characteristics of the fluid material (hot water) in the tube are the following ones:
density $\rho_f=0.75\cdot 10^3\,kg/m^3$,
speed of sound $c_f=10^3\,m/s$.

The physical characteristics of the materials constituting the piston of wall and the pistons of end play only one formal part in the computation of *Code_Aster*.
These physical characteristics of material are the following ones:
Poisson's ratio, Young $E=2.10^{12}\,Pa$ modulus
$\nu=0.3$,
density $\rho_s=0\,kg/m^3$.

1.3 Characteristics of springs, masses and dampers

the characteristics of the piston of wall as an oscillator are the following ones:

Stiffness	$K=5.10^{10}\,N/m$
Masses	$M=200.10^3\,kg$
Damping	$A=0\,Ns/m$

the characteristics of the pistons of end as oscillators are the following ones:

Stiffness	$k=0\,N/m$
Masses	$m=0\,kg$
Damping	$a=\rho_f c_f S=37.5\,10^4\,Ns/m$

1.4 Boundary conditions and loadings

infinitely rigid Piston of wall and with displacement only according to the vertical axis.

Infinite length of fluid thus not of reflection of end of the waves: this boundary condition is simulated in the model by a piston at each end, of mass null, moving only according to the axis of x and provided with a damper with adequate damping; these pistons are moreover more infinitely rigid.

Total reflection of the waves on infinitely rigid walls of the fluid tube: realized simply while omitting to model the wall by structural elements.

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2 Reference solution

2.1 Method of calculating used for the reference solution

the goal is to determine the temporal displacement $z(t)$ of the piston of wall.
One considers the plane problem of this meridian model whose geometrical, mechanical and fluid characteristics are described on the figure [Figure 1.1-a]; the side piston is length $2L$.
The two-dimensional problem is brought back to a monodimensional problem by considering by approximation that the rates of transverse flow $\dot{z}$ induced by the motion of the piston are transmitted instantaneously out of axial velocities in the channel.
In the control volume $d\Omega = edx$ of extended dx under the piston of wall one can write:

$$d(\delta V)=\frac{1}{2e}dx\,d\dot{z}$$

In the fluid variation velocity and variation of pressure in adiabatic evolution are connected by:

$$\delta P=\rho c\,\delta V$$

The pressure at time t in a point of X-coordinate x results from the superposition of the propagation of all the elementary sources distributed on the piston:
The coupling thus consists of this: the motion of the piston of acceleration $\ddot{z}(t)$ induced in the channel a field of pressure $P(x,t)$ whose force resulting on the extent from the piston itself acts as return on the dynamics of the oscillator.

The geometrical, mechanical characteristics and fluids of the model are presented on the figure [Figure 1.1-b].
It is considered initially that the piston and the fluid are at rest and one carries out to release oscillator at time $t=0$ by imposing an initial velocity to him.

The statement of the pressure $P(x,t)$ in a point of the channel develops:

$$P(x,t)=\frac{\rho c}{2e}\int_0^t\left[\int_{-L}^{x}\ddot{z}(\tau-\frac{|x-u|}{c})du+\int_{x}^{+L}\ddot{z}(\tau-\frac{|u-x|}{c})du\right]d\tau$$

However one has $z(0)=0$ and $z(t)=0$ for t negative, and

$z(-\frac{L-x}{c})=0$ since upstream of the piston (x including enters $-L$ and L) the quantity between bracket is always negative; for the same reason one A. $z(-\frac{L+x}{c})=0$

Finalement it comes:

$$P(x,t)=\frac{\rho c^2}{2e}\left[2\,z(t)-z(t-\frac{L-x}{c})-z(t-\frac{L+x}{c})\right]$$

One integrates this statement on *X* in order to obtain the resultant of the compressive forces on the piston:

$$R(t)=-H\int_{-L}^{+L}P(x,t)dx=-2H\int_0^L P(x,t)dx\ :$$

Indeed $P(x,t)$ is even in x ; it is thus enough to integrate on half of the piston.

From where the statement of the resultant of the compressive forces on the piston on the assumption of small motions:

$$R(t)=-\frac{H\rho c^2}{e}\left[2L\,z(t)-c\int_{t-\frac{2L}{c}}^{t}z(u)du\right]$$

The motion of the oscillator thus obeys the equation:

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$$M\ddot{z}+Kz+\frac{2HL\rho c^2}{e}z-\frac{2HL\rho c^2}{e}c\int_{t-\frac{2L}{c}}^{t}z(u)du=0$$

or:

$$M\ddot{z}-F_{int}-F_{coupl}=0$$

if one poses:

$$F_{int}=-Kz-\frac{2HL\rho c^2}{e}z \quad \text{and} \quad F_{coupl}=\frac{2HL\rho c^2}{e}c\int_{t-\frac{2L}{c}}^{t}z(u)du$$

One now considers the case of the propagation of one wave decompression at stiff front of amplitude ΔP_0 along the conduit. At time $t=0$, this wave still attacks the piston of wall at rest, creating on this piston a force of excitation such as:

$$F_{excit}=\begin{cases} H\,c\,t\,\Delta P_0 & \text{si} \quad t<\frac{2L}{c} \\ 2\,H\,L\,\Delta P_0 & \text{si} \quad t\geq\frac{2L}{c} \end{cases}$$

The equation of motion is written then:

$$M\ddot{z}=F_{int}+F_{coupl}+F_{excit}$$

This equation is solved numerically with the Matlab *software* for the characteristics presented of the meridian oscillator.

2.2 Result of reference

Displacement $z(t)$ of the piston of wall.

2.3 Uncertainty of the analytical

solution Solution.

2.4 Bibliographical references

1) F. STIFKENS: “Transient computation in *the Code_Aster* with the vibro-acoustic elements”. Note intern R & D HP-51/97/026/A.

2) F. TEPHANY, A. HANIFI, C. LEHAUT: “Elements of analysis of the interaction fluid-structure in annular space tank-envelope of heart in the event of APRP” - Notes intern SEPTEN ENTMS/94.057.

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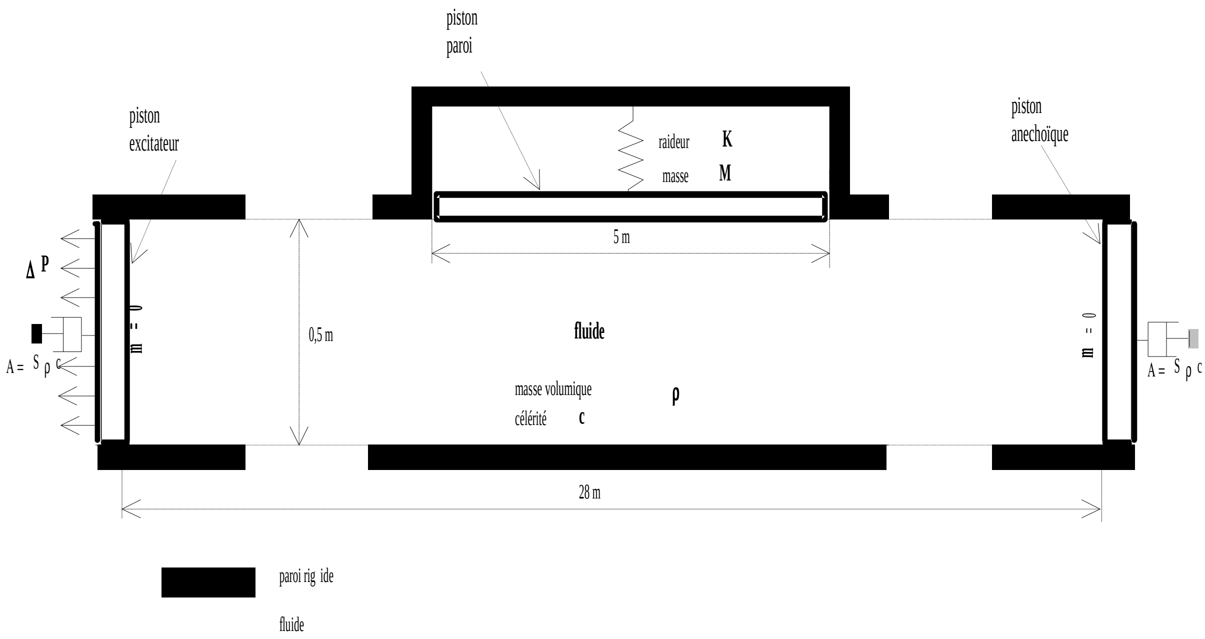
3 Modelization A

3.1 Characteristic of the vibro-acoustic

3.1.1 modelization System are equivalent modelling

In order to avoid the waves of return coming from the ends of a modelization inevitably of finished size one provides these ends with systems “piston-damper” as on the figure [Figure 3.1.1-a].
The channel is modelled over an overall length of $28\,m$ sufficient to obtain with certainty, at least the two first extrema of the curve of displacement of the piston without disturbance of one wave reflection at the ends.



Appear 3.1.1-a: Vibro-acoustic system are equivalent

3.1.2 numerical Modelization in finite elements of *Code_Aster*

One chose to model in 2D.

For the fluid : the modelization is in formulation p, ϕ .
It is carried out by the assignment on meshes of type `QUAD4` (quadrilaterals with 4 nodes) of elements `PHENOMENE = ' MECANIQUE', MODELISATION = ' 2D_FLUIDE'`.

For structures : the modelization is in formulation $\boldsymbol{u}$.
It is carried out by the assignment on meshes of type `QUAD4` (quadrilaterals with 4 nodes) of elements `PHENOMENE = ' MECANIQUE', MODELISATION = ' D_PLAN'`.
For the discrete elements of oscillators : the modelization is in formulation $\boldsymbol{u}$.
It is carried out by the assignment on meshes of specific type `POI1` of elements `PHENOMENE = ' MECANIQUE', MODELISATION = ' DIS_T'`.

For the interfaces fluid-structure : the modelization is in formulation $\boldsymbol{u}, p, \phi$.
It is carried out by the assignment on meshes of type `SEG2` (segments with 2 nodes) of elements `PHENOMENE = ' MECANIQUE', MODELISATION = ' 2D_FLUIDE_STRU'`.

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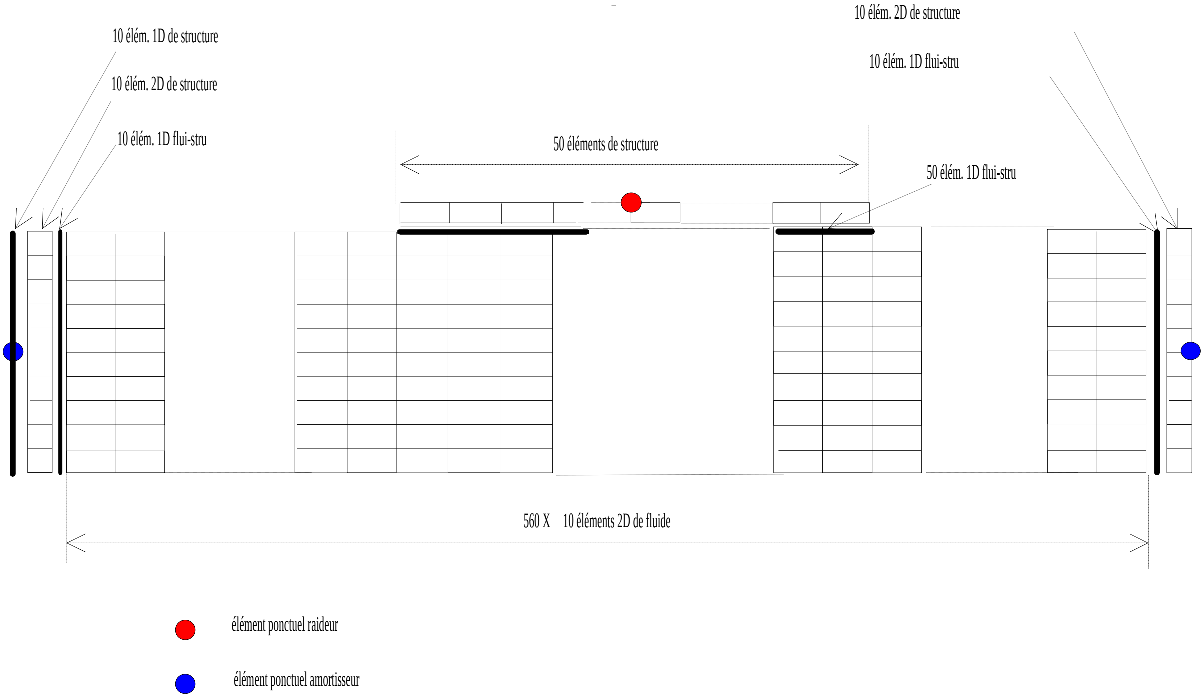
3.2 Characteristics of the mesh



Appears 3.2-a: Two-dimensional mesh of the model of oscillator fluidelastic

One gathered in the table hereafter, the data characterizing this modelization.

	Type of mesh			total
	Number	QUAD4	SEG2	POI1
Many elements	2870	80	3	2953
Many generated nodes	3164	0	0	3164

Table 3.2-1: Characteristics of the two-dimensional mesh of the oscillator fluidelastic

3.3 Computation

One wishes to validate the elements of interaction fluid-structure in transient regime by a loading of excitation. One carries out the computation of the displacement of the piston of wall with operator `DYNA_LINE_TRAN`.

3.4 Quantities tested and results

the results of computation with *Code_Aster* are presented graphically on [Figure 4.1-a] in superposition with the “analytical” reference solution.

The curve of *Code_Aster* appears very close to the reference during the first 4 oscillations but the differences, at the same time in amplitude and phase, are increasingly perceptible when T increases.

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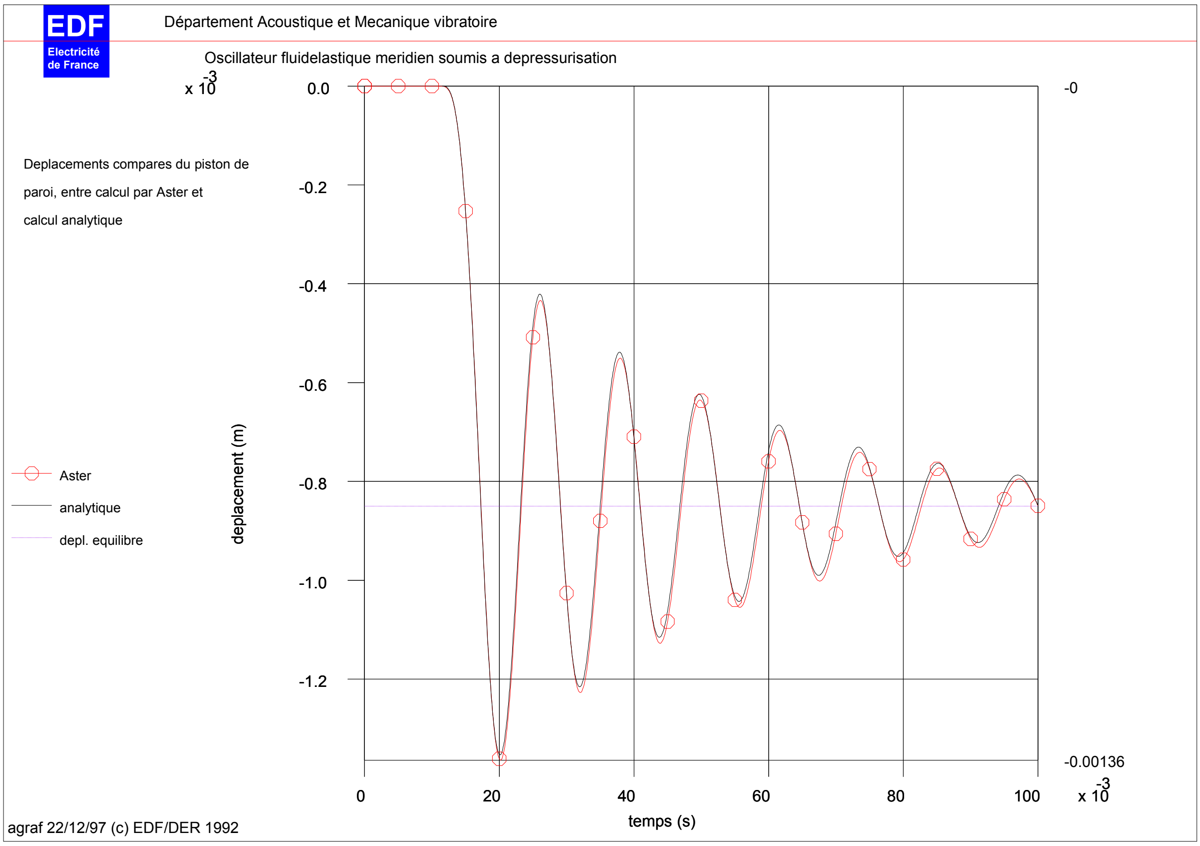

Appear 4.1-a: Comparison between computation *Code_Aster* and reference the semi analytical

test relates to the displacement of the piston of wall in two times given close to the two first extrema.
The table presents comparative of the 2 first extrema curve of displacement of the piston between analytical points and points calculated by *Code_Aster*.
The values obtained of times of extrema in one and the other case are values considered extracted without interpolation rough computed values: they do not correspond exactly between the analytical curve and the curve of *Code_Aster*.
One compared to the estimates the tolerance of variation relative analytical value to 1.%.

	Analytical reference	
	Inst. (ms)	Dépl. (mm)
1st Extremum	20,13	– 1,3530
2nd Extremum	26,05	– 0,4210

Test of non regression of the code:
the tolerance of relative variation compared to the reference is worth 0,1%.

3.5 Notice

the values of reference finally selected those are obtained by *Code_Aster* during the restitution of the benchmark, which will thus make it possible to check non regression later code during its evolution.

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4 Summary of the results

Good accuracy over the first periods then light error in amplitude and phase due to the influence of integration in numerical time Newmark $\left(\alpha=\frac{1}{4},\gamma=\frac{1}{2}\right)$.

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