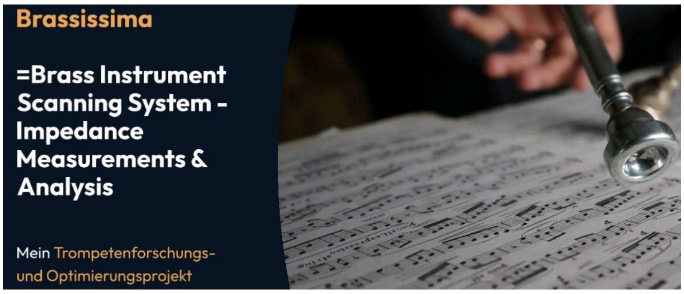
Openwind Simulations of a closed-open cylindrical tube which is systematically perturbated, Examples and Results

12.7.2024

This short summary report is part of experiments, made with simulation software and also measurements done with a measuring head on simple tubes and complete brass instruments, at my private trumpet research project called brassissima. The whole research and documentation can be found at www.preisl.at/brassissima/



The Openwind project

Openwind
Python library assisting instrument makers

can be found here: https://openwind.inria.fr/

Content:

Appendix:

Description of the experimental setup and applied changes / simulations:

The experiment consists in simulating and measuring a cylindrical tube that is closed on the left and open on the right end, with a length of 1.0m and an internal cross-section Diameter of 10 mm in the example as a reference. Here are the results of the simulations done with Open Wind.

We are looking for the changes in input impedance magnitude = modulus = amount |Z| at the closed end, and also the change in frequency of the resonant modes, that occur when the tube is locally systematically disturbed (perturbated).

exemplary: Centered Perturbation Pos.= 50% of tube lenght:
closed end x=500mm open end
jump to Perturbation; **jump back** to boresize
x=0 .... at x= 490mm ...|... at x=510mm ....x=1000mm

Enlargement, lenght= 20mm, centered at x=50% tube lenght: q0= 1,1
y Dia 10mm -> y=Dia 11,0mm y=Dia 10mm -> Dia 10mm

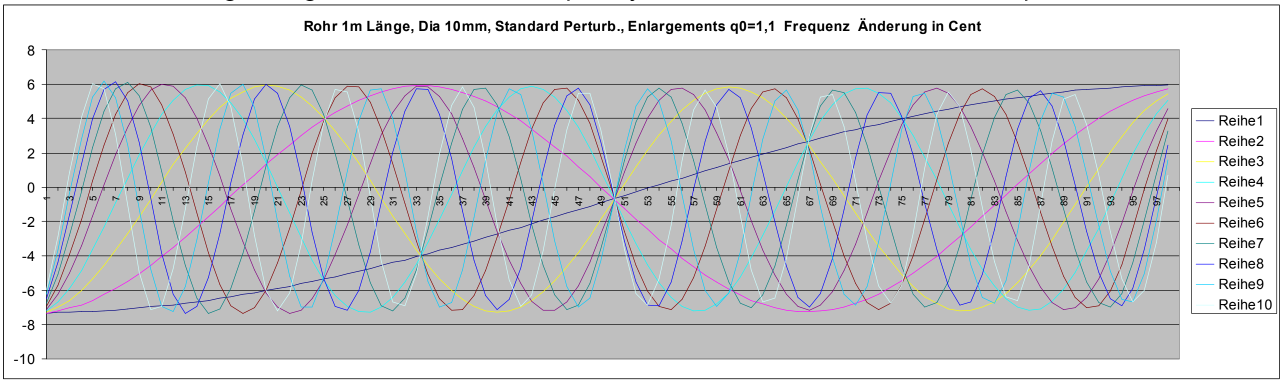
Constriction, lenght= 20mm, centered at x=50% tube length, 1/q0= 0,90909:
y Dia 10mm -> y=Dia 9,09mm y=Dia 10mm -> Dia 10mm

Now, a complete run of the experiment is, that the perturbation center position is stepwise changed and repeated 98 times, from center pos. x=10mm stepwise to x = 990mm = 98 simulations, 98 measurements, the perturbation length and the change in cross-sections stays as defined, so the perturbation itself has the same overall “disturbating – volume power”, but it is found that its position – and so the situation of the air colums left and right from it are the real parts which do a fight against each other giving following results.

Each simulation (or / and) measurement of these series shows the changes at each 1 % step in direction from the closed to the open end, when such perturbations are stepwise drawn trough the tube.

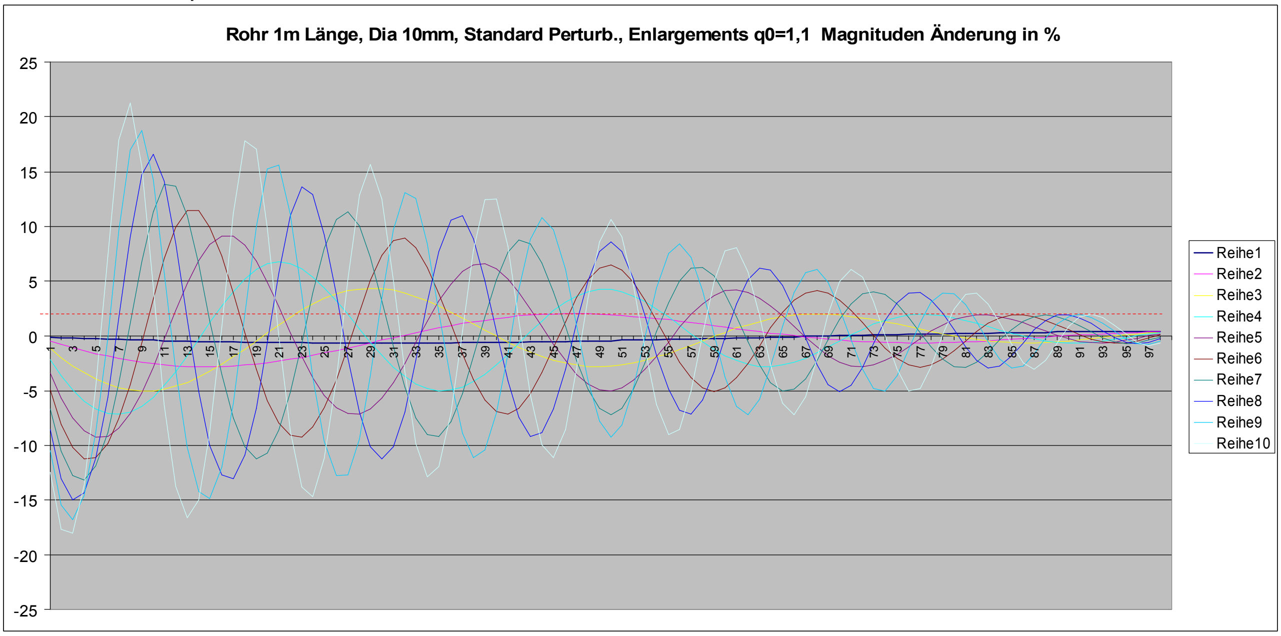
Results of local enlargements, Open Wind Simulation:

Here is the resulting change of the resonant frequency of the modes #1-#10, with the open wind simulation.



x is the centered perturbation position in % of tube lenght, y is the difference in cents due to the perturbation.
The boresize is Dia 10mm, the local enlargement is Dia 11mm, gives q0= 1,1 cross-sectional factor.
the “standard length” equals in my former experiments to = 2,0% tube length.
What very quickly found is, that the pitch-changes have the same potential on all modes and there is more lowering potential.

Here is the resulting changed Input Impedance Magnitude = Modulus of the modes, in % change, found with the open wind simulation:

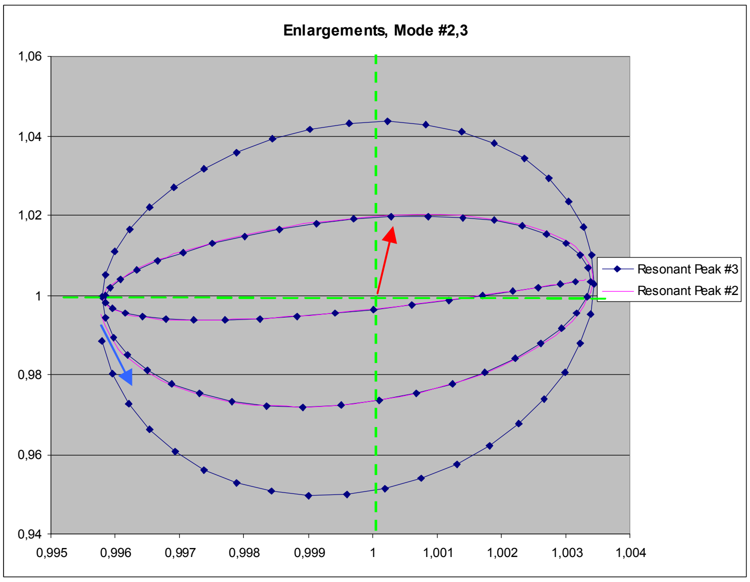


x is the centered perturbation position, y is the difference in % Input Magnitude Change due to the perturbation, the boresize is Dia 10mm, the local enlargement is Dia 11mm,
Standard perturbation length equals to = 2,0% tube length.

The red dotted line shows exemplary 3/8 wavelenght “Magnitude change pot.”, the Magn. pot found by simulation at a distance of 3/8 wavelenght (from mode #2 up); from the (rightside) open end of the tube.

This gives points at perturbation center = x, where a local maximal change in Input Impedance is found and, also the maximal change in resulting frequency – both are changed because of the local perturbation (and of course the positions, where there are the “zero crossings”, what I call nodes (Frequency = Pitch nodes, Magnitude changes 0%= Magnitude nodes.)

The foregoing data represents the changes of the found Impedance-Maxima Peak due to perturbation.
Now it is also possible, to show both regimes changes at once / at the same time = perturbation location:



(Open Wind data as before)

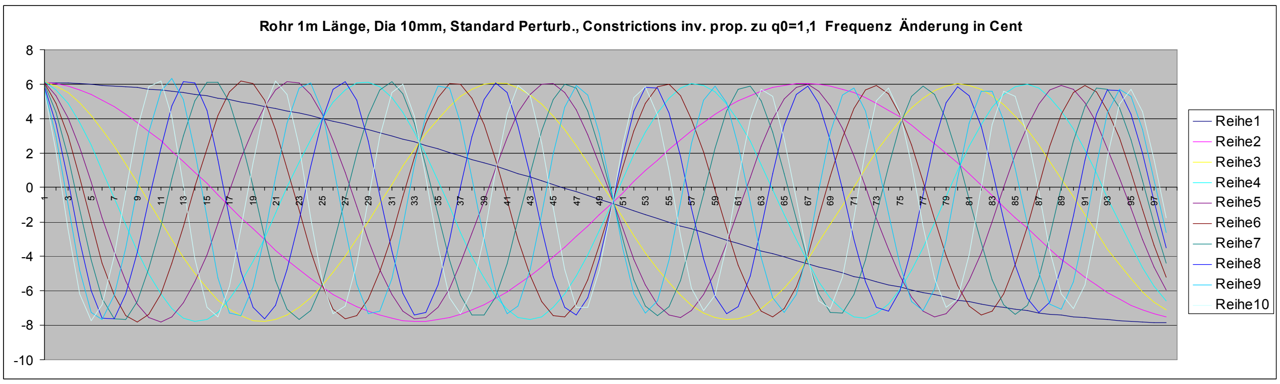
here x and y are shown as (change) ratio to the non perturbated tube. (a trace of the peak maxima). Each data point represents 1% of tubelenght from the closed end.
x-axis = frequency factor of change, y-axis =|Z|in magnitude factor of change due to the perturbation. The blue arrow indicates the starting position at x= closed end (left) and the direction to the open end. The red arrow shows the position 3/8 wavelenghts – and the pot - but now - from the open end.

The unperturbated positions of the Peaks would be (unchanged) at coordinates x=1,0 und y=1,0. The rotation around x=1,0 and y=1,0 shows the assumed changes of openwind due to the perturbations. x = 1,0 equals a “pitch node”, y= 1,0 equals a “magnitude node” – meaning no changes.

Because of the changes which are along the tube, a zero crossing must mean a position, where forces have a balance of power, so there would be an offset and zero crossings are on positions with an offset to x and y.

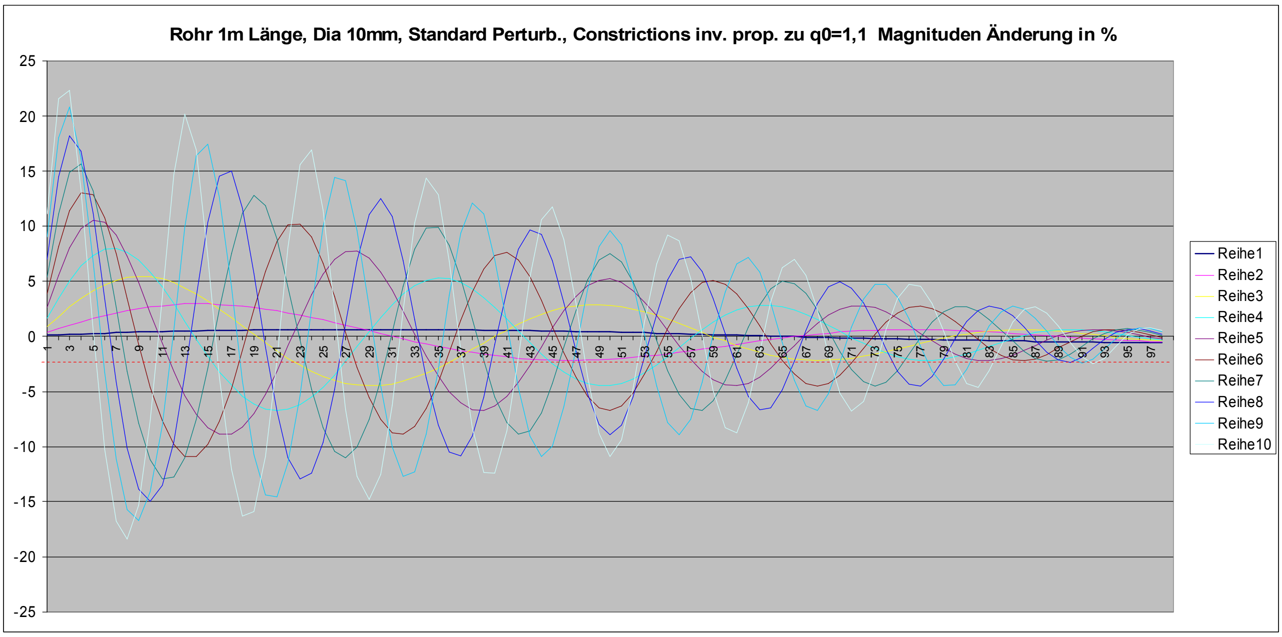
I have now to state that, when the peak maxima values are “traced”, the resulting deviations make always a counter clockwise rotation when the perturbation series start at the closed end an finish at the open end. The change in input magnitude is much larger near the closed end, so this gives some sort of what I name a “spiral view” of the peak maxima changes.

Results of local constrictions, Open Wind Simulation:



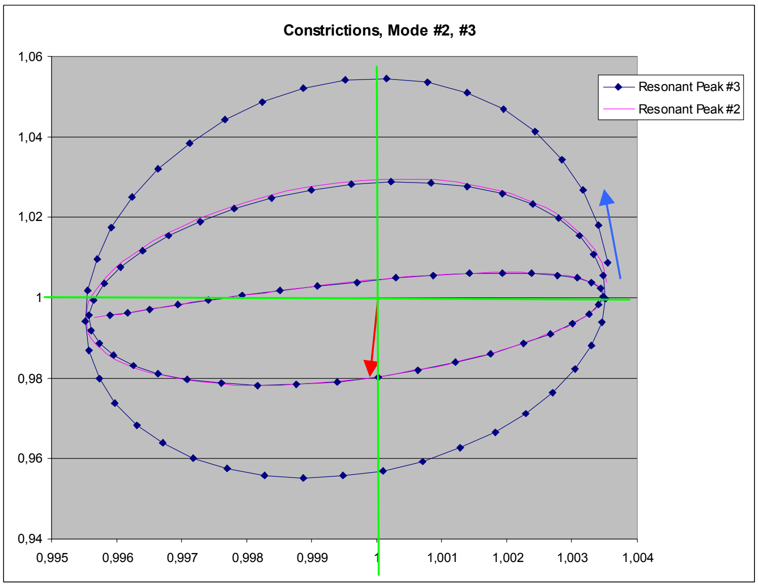
x-axis = centered perturbation position in % of tube length, y-axis: frequency changes (in cents)
The boresize is Dia 10mm, the local constrictions are 10mm/1,1=9,0909mm, (inverse prop. to enlargements)
“Standard perturbation length” equals in my former experiments to = 2,0% tube length.

What is very quickly found is, that the pitch changes have the same potential on all modes and almost the same stronger lowering pot. and it can be stated: Raising pitch pot is = q0² less strong then lowering pot. and if constrictions are choosen to be inverse prop. to enlargements, they have the same pitch pot. (However, constrictions show a very slighty more pot down in the Open Wind simulation).



x is the centered perturbation position, y is the difference in % Input Magnitude change due to the perturbation, the boresize is Dia 10mm, the local constriction is Dia 9,0909 mm,
Standard perturbation length equals to = 2% tube length

Red dotted line shows exemplary 3/8 wavelenght “Magnitude change pot.”, the pot found by simulation at a distance of 3/8 wavelenght (from mode #2 up); from the (rightside) open end of the tube.



The resulting deviations when tracing the Peak Maxima changes make always a counter clockwise rotation when the perturbation series start at the closed end and finish at the open end. It shoud be visible, that the mentioned 3/8 wavelenght pot. and the overall behaviour – (when viewed from the open end) can be said to be identical at all modes (in the Open Wind Simulation). Blue Arrow shows starting position at closed end, the red arrow shows the position at 3/8 wavelenghts from the open end.

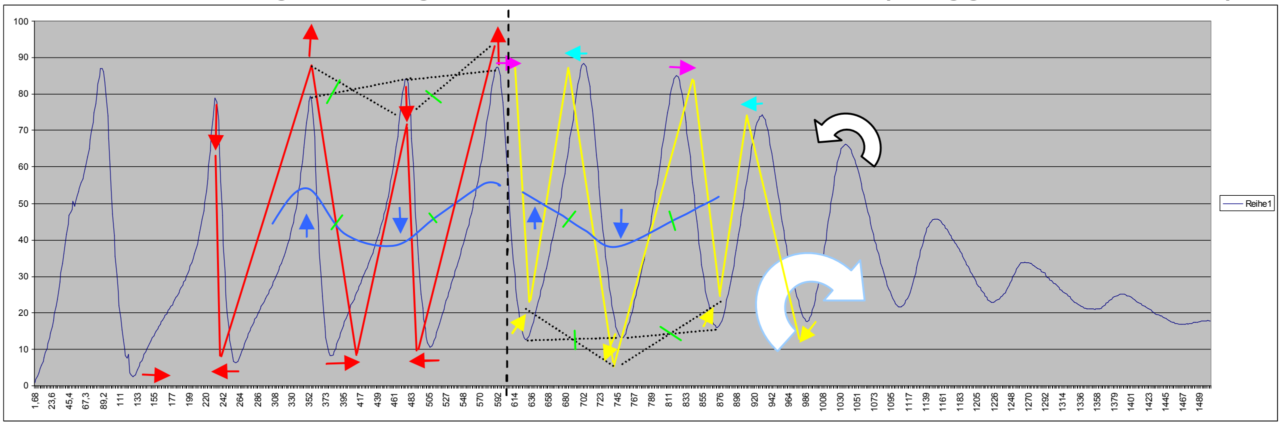
So what is found, there are 2 regimes: Impedance Peak Frequency Pot (changes) correlates strongly with Impedance Minima Magnitudes, Impedanz Peak Magnitude Pot correlates strongly with Impedance Minima Frequency (changes). Minima are so “shared” by Resonances, they are below or above …and react as an effect so inverse to each other.

This is also still the case in a much more complex geometry (trumpet), here in the next section only shown in a very schematic drawing, and here is also shown, how the absolutely "not" resonating frequencies = the traced antiresonances behave: Minima changes turn clockwise at the same time (progress perturbation positions)!

Perturbations – Effect on the entire resonances and its neighbouring peaks

Perturbations do not only effect the peak maxima, but the entire resonance, including minima before and after and thus neighboring frequencies that share the minima. Changes in the minima are larger. Note the difference between ODD and EVEN # modes at these specific "functional" positions!

Schematic drawing of changes due to local Constrictions (exaggerated, Trumpet):



Left part of the Diagram:
at position xm-pitch(nodes) = the position at "some" the acoustic middle of the whole instrument
in a strict closed-open cyl., this equals to position 50% of tube length.

Red = **Constrictions at XM-Pitch** **Peaks -> Magnitude change**, Minima -> Frequ. change
Odd Mode # grow at the expense of even modes #.

Right part of the Diagram:
at position xm-in1 = (impedance nodes); the position closer to the closed end, near a pressure node or pressure antinode before the position of xm–pitch
in a closed-open cyl., this pos. is ~1/8 wavelenght before 50% tube length.

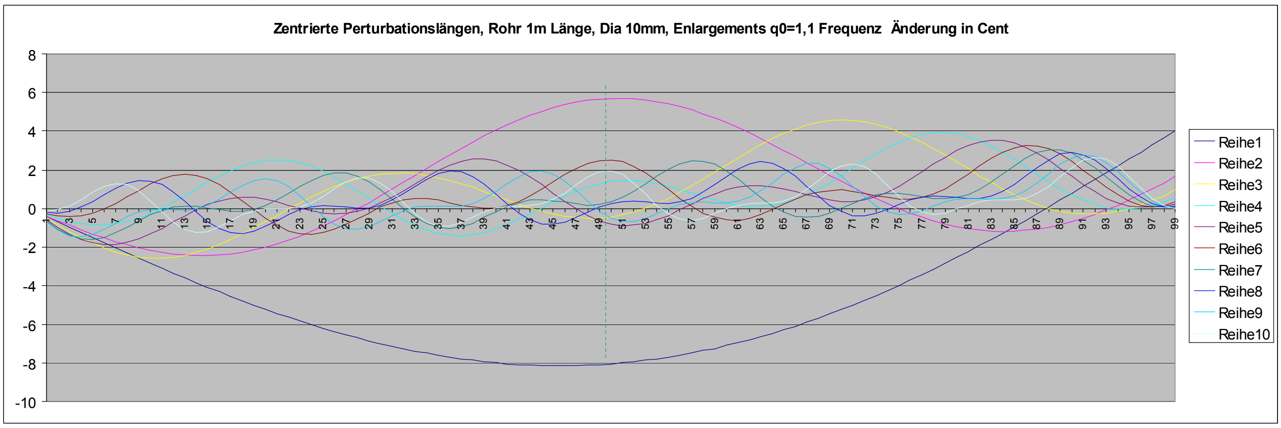
Yellow = **Constr. at XM-IN1** Peaks -> Frequency change, **Minima -> Magn. change**
Orange: **ODD # = Press. Antinodes.**, **EVEN # = Press. Nodes**

Blue = wave impedance at XM-Pitch changes with Peak Maxima, same direction
wave impedance at XM-IN1 changes with Minima, same direction
in between at the flanks different.

black arrow: Direction on rotation Peaks and Waveimpedance, from Mouthpiece to Bell end
light blue arrow: Direction of rotation Minima (more Pot.), from mouthpiece to Bell end.

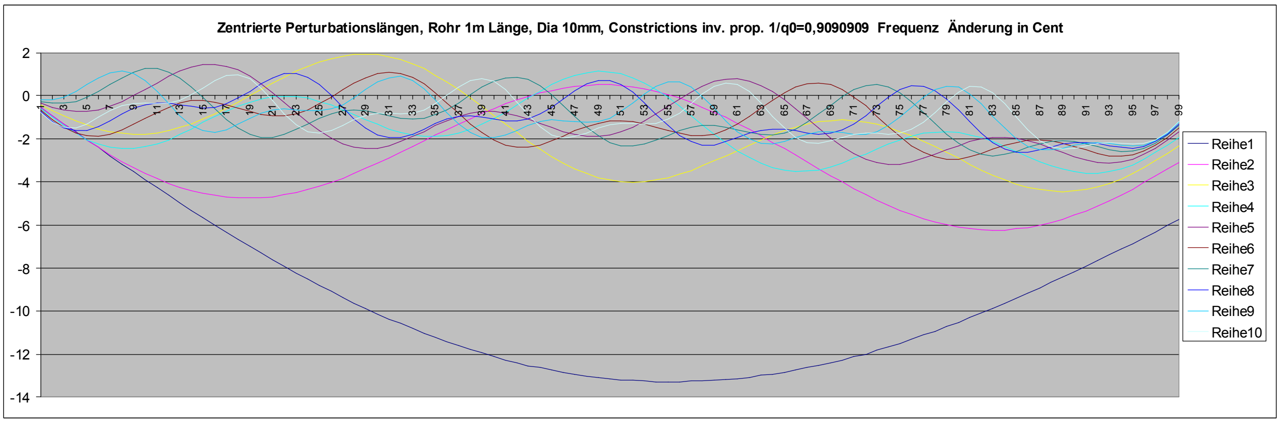
The Pitch potential of perturbation lenghts, when centered at 50% tubelenght:

We should remember that a centered Perturbation at 50% Tube length behaves to be a ~Pitch Node, if the perturbation is (much) smaller then ¼ wavelength of the mode. This is not the case with longer perturbations:

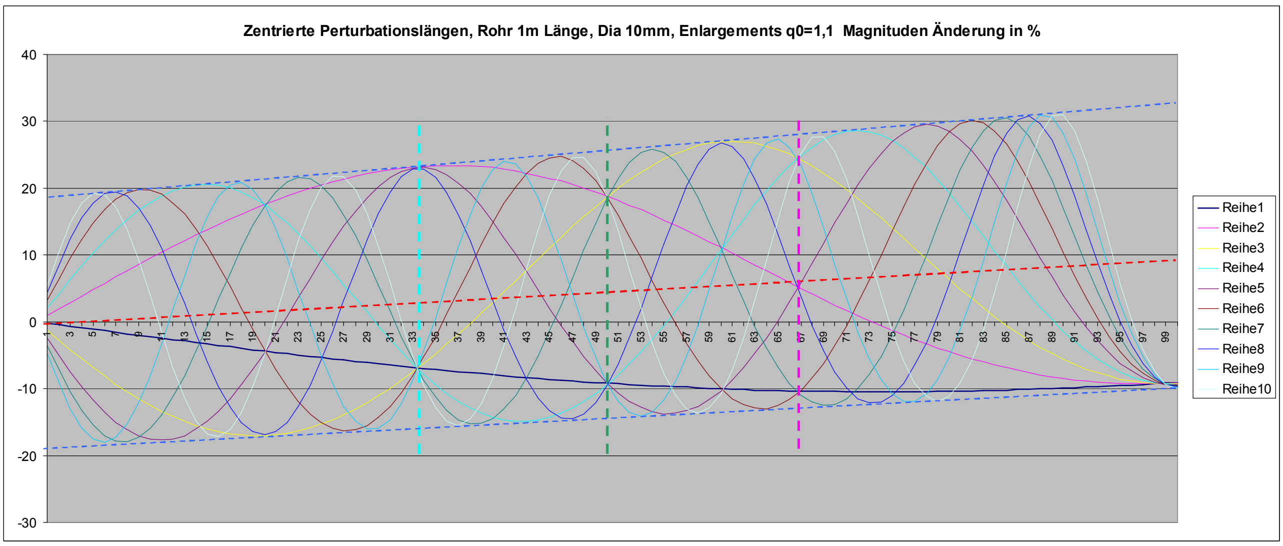


the perturbation center position is here always = 50% of tube length,
y = Frequency change in cent with x = perturbation length in % of tube length
- the largest pitch pot arises with a centered perturbation length, where the remaining not perturbated tubelenght = 3/8 wavelengths TL = 3/16 WL before and 3/16 WL after the perturbation.
Such Pitch pot is "inverse", *but if one is looking in largest pitch pot … boresteps are the answer!*
Mode #1 deviates from this and has a remaining unperturbated tube length of >1/8 WL total, this pot. is not inverse, and a found inv. pot is ½ the non inverse pot. wenn the whole tube is enlarged.

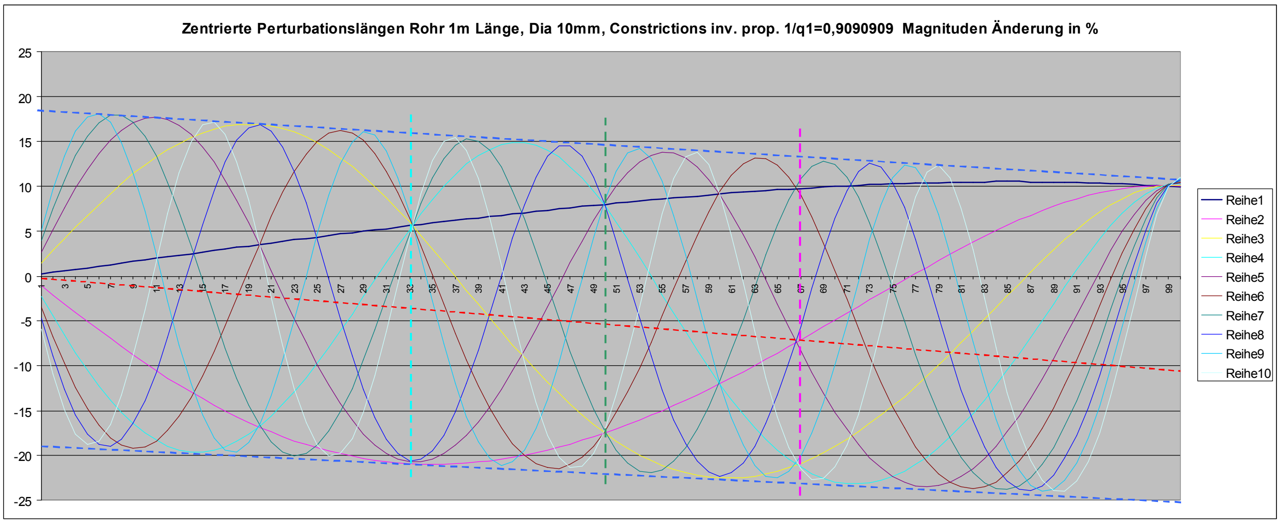
Constrictions:



with centered constrictions, the results are very different, interesting, what mode #1 does; it is not raised…



Input Magnitude changes with enlargements, x = length of centered perturbation in % of tube length



Input Magnitude changes with constrictions, x = length of centered perturbation in % of tube length

If the centered perturbation length becomes = tube length, the magnitude change is in the relationship to the sqare root of the cross sectional area changes (as ratio). $\sqrt{q0^2} = q0$.
q0 is defined as the ratio of the different diameters (or radius). $q0^2$ is the ratio of area change.

In the case of a full boresize – enlargement q0=1,1 the input magnitudes change inverse prop. to 1/q0 = 0,90909 = -9,09% change.

In the case of a full boresize – constriction 1/q0=0,90909m the input magnitudes change inverse prop. to q0= 1,1 = + 10,0% change.

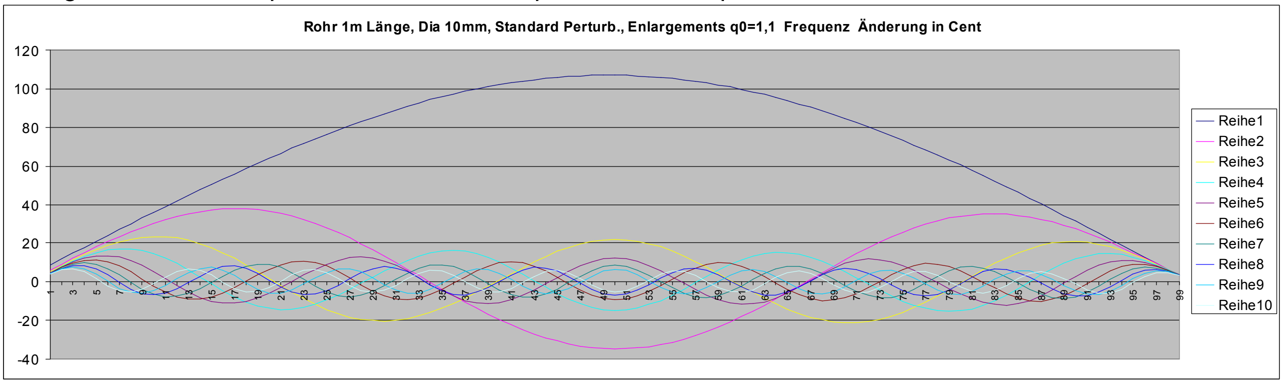
(There is a small increased change found at high mode #). You may also notice some “over-pot” of mode #1, this is detailed in other parts of my documentation.

Note: The inner lateral surface ratio equals the ratio of q0, when perturbations are radial symmetric applied (sleeve-type), with is not the case, when constrictions are performed in “inserting” solid bodies into the tube!

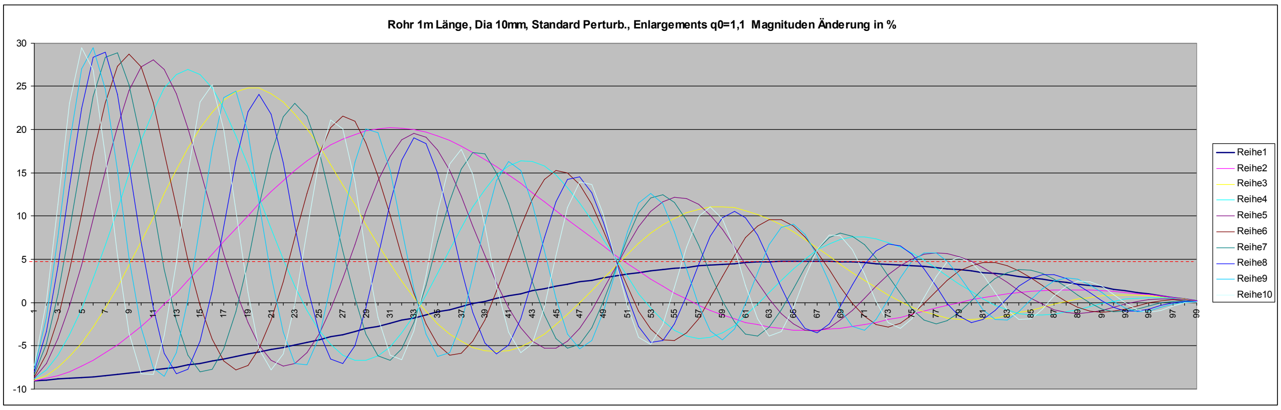
Actually, in simulation only the “sleeve” type perturbations can be calculated. Changes due to for example inserted solid bolts are under investigation.

The effects of boresteps:

Enlargements on the open side of the tube = positive boresteps:

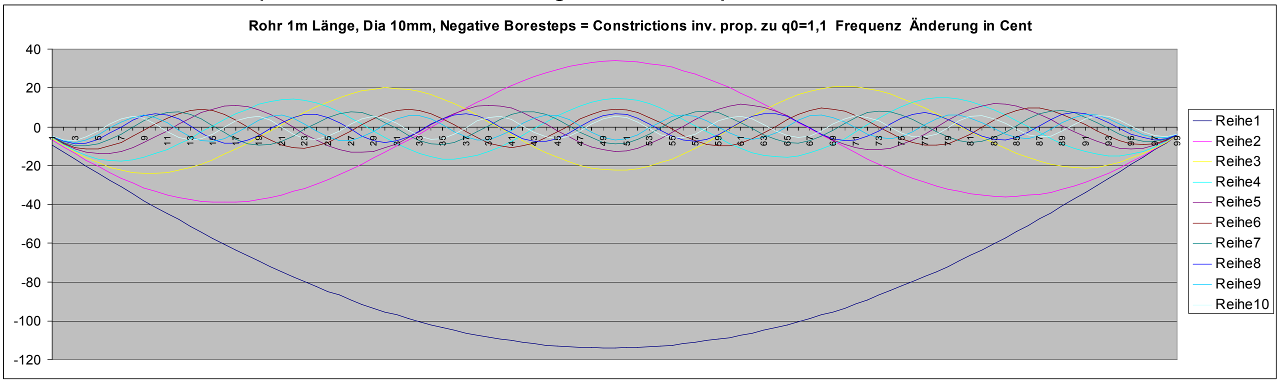


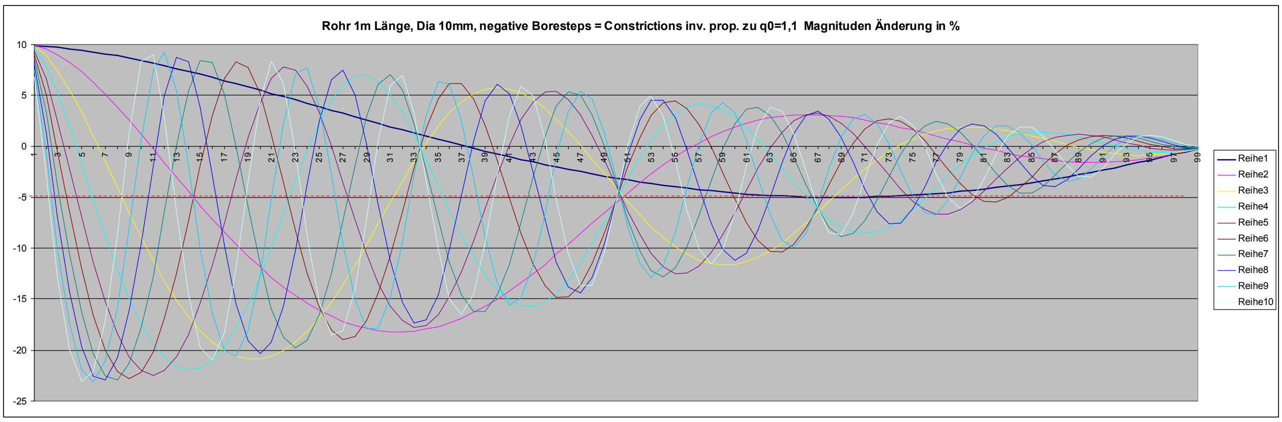
x = the position of the borestep in % of tube length, here the side with the open end is enlarged.
Notice the <u>very strong Pitch Pot</u>., Modes # Pot is ~ Mode#/odd Mode # with a step at 50% tube length ..



x = the position of the borestep in % of tube length, here the side with the open end gets enlarged.

Constrictions on the open side of the tube = negative boresteps:





Appendix: Extended Python script used:

```
#!/usr/bin/env python3
# -*- coding: utf-8 -*-
# Copyright (C) 2019-2023, INRIA
# This file is part of Openwind.

import numpy as np
import matplotlib.pyplot as plt

from openwind import InstrumentGeometry
from openwind.continuous import radiation_model
from openwind import ImpedanceComputation

# %% following section opens the file geometrie.txt than replaced decimal comma , with . and
# and writes this to a new  file called instrument.txt
# read file
with open('geometrie.txt', 'r') as file:
  lines = file.readlines()
# replace commata with dots:
  lines = [line.replace(',', '.') for line in lines]
# write changes to instrument.txt overwriting existing content
with open('instrument.txt', 'w') as file:
  file.writelines(lines)

# %% Basic computation
# Frequencies of interest: 0Hz to 2kHz by steps of 0,3333 Hz using mm and diameter instead of radius
fs = np.arange(10, 2000, 0.333333)
geom_filename = 'instrument.txt'


# Find file 'instrument' describing the bore, and compute its impedance, set temp in C, parameter carbon std
result = ImpedanceComputation(fs, geom_filename, temperature=23.0, humidity=0.3,
radiation_category='unflanged', compute_method='FEM', discontinuity_mass=True, spherical_waves=False,
nondim=True )

# you can get the characteristic impedance at the entrance of the instrument
# which can be useful to normalize the impedance
Zc = result.Zc

# %% other useful features
# you can print the computed impedance in a file.
# It is automatically normalized by Zc
result.write_impedance('computed_impedance.txt')

# %% following section opens this file, replaced . with , and write new file as txt file

# read Text file
with open('computed_impedance.txt', 'r') as file:
    lines = file.readlines()

# Replace Dezimalpunkte with Commata for easy import to Excel
lines = [line.replace('.', ',') for line in lines]

# Write new file
with open('spectrum.txt', 'w') as file:
    file.writelines(lines)

#Plot Geometrie of instrument.txt
my_instru_from_files = InstrumentGeometry('instrument.txt')
my_instru_from_files.plot_InstrumentGeometry()
plt.show()
```

```
# Display resonance frequencies
N = 20 # maximal number of printed frequencies
f, Q, Z = result.resonance_peaks(N)
nb = len(f)
for i in range(0,nb):
    print(f" {i+1:2d} - Resonance frequency : {f[i]:4.2f} Hz, Quality factor : {Q[i]:3.2f}, Scaled amplitude : {np.abs(Z[i])/result.Zc:3.2f}")

# Plot obtained impedances
fig=plt.figure(1), plt.clf()
result.plot_instrument_geometry(figure=plt.gcf())

fig=plt.figure(2)
plt.clf()
result.plot_impedance(figure=fig)
ax=fig.get_axes()
ax[0].plot(f, 20*np.log10(np.abs(Z/result.Zc)),'r+')
ax[0].legend(['modal computation','modal estimation'])
plt.xlim([fs[0],fs[-1]/2])
ax[1].plot(f, np.angle(Z/result.Zc),'r+')

# Display resonance frequencies
N = 20 # maximal number of printed frequencies
f, Q, Z = result.resonance_peaks(N)
nb = len(f)
print("")
print("")
print("Peak Magnitude Q-Faktor:")
for i in range(0,nb):
    print(f"{f[i]:4.3f} {np.abs(Z[i]):9.0f} {Q[i]:3.2f}")

# Open a file in write mode to save the output with dots as decimal character
with open('peaks_out.txt', 'w') as file:
    file.write("Peak Magnitude \n")
    for i in range(0, nb):
        line = f"{f[i]:4.3f} {np.abs(Z[i]):9.0f} \n"
        file.write(line)

# %% following sections replaces dots with comma for an easier Excel import, writes new file

# Read text file
with open('peaks_out.txt', 'r') as file:
    lines = file.readlines()

# replace dots with commata
lines = [line.replace('.', ',') for line in lines]

# write in new text file
with open('peaks.txt', 'w') as file:
    file.writelines(lines)

print("peaks.txt und spectrum.txt are done!")
print("Zc in Ohm:")
print(result.Zc)
```

Appendix: Some Examples of geometrie.txt

These files define the inner dimensions of the tube, and the perturbations:
(geometrie files are converted to instrument.txt file, where comma are replaced with dots).

```
# this content describes the non perturbated tube, used as reference
! unit = mm
! diameter = True
#Pos x     # dia y    in mm
0          10,0
1000       10,0
```

```
# this contains an enlargement to dia 11mm, perturbation length =20mm, centered at 50% tube lenght
! unit = mm
! diameter = True
#Pos x # dia y    in mm
0          10,0
490        10,0
490        11,0
510        11,0
510        10,0
1000       10,0
```

```
# this contains an enlargement to dia 11mm, perturbation length =20mm, centered at 2% lenght
! unit = mm
! diameter = True
#Pos x # dia y    in mm
0          10,0
10         10,0
10         11,0
30         11,0
30         10,0
1000       10,0
```

```
# this contains a constriction to dia 9,0909 mm, perturbation length=20mm, centered at 2% lenght
! unit = mm
! diameter = True
#Pos x # dia y    in mm
0          10,0
10         10,0
10         9,090909
30         9,090909
30         10,0
1000       10,0
```

```
# this is a tube with inner diameter = 10mm and a positive borestep to 11mm, at position 50% of tube lenght
! unit = mm
! diameter = True
#Pos x # dia y    in mm
0          10,0
500        10,0
500        11,0
1000       11,0
```