DML basics and material graph

ChristianV (Homeswinghome@diyAudio)

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Abstract

The choice of the material for the membrane of a Distributed Mode Loudspeaker is a key point. This paper gathers the inputs from the vibrating plate theory encountered in the papers about DML. This paper proposes also graphical representations of the material properties.

Contents

Disclaimer : this paper is written in the context of DIY DML building with the target to identify some design rules to help in the panel construction by the membrane material choice. This document is not written in the context of any academic or scientific work. Its content is reviewed only by the feedback it can get while posting

it in audio DIY forum like diyAudio. It might be too simplistic, nevertheless it proposes an introduction to go to DML design rules.

The pdf format of the paper is directly extract from a python script used to plot the charts. See Github py2pdf for more information about this method.

1 Introduction

The key point of DML (Distributed Mode Loudspeaker) is the membrane, its material, its dimensions.

Scientific papers about DML like [1] and many others point to plate vibration theory as a scientific basis.

The important characteristics of the membrane material are:

- ρ : density in kg/m³ (only SI in this paper ;-))
- E : Young or tensile modulus in Pa (Pascal = N/m²) or more communally in MPa or even GPa
- h : the plate thickness in m

2 From the plate vibration theory

2.1 Stiffness B and areal mass μ

The plate vibration theory introduces two quantities that simplify the equations:

- B : the bending stiffness in Nm
- μ : the areal mass in kg/m²

$$B = \frac{Eh^3}{12} \tag{1}$$

$$\mu = \rho.h \tag{2}$$

For a material with a high enough shear resistance G (okay this is something to define!) :

$$\nu = \sqrt{2\pi f \sqrt{\frac{B}{\mu}}} \tag{3}$$

ν m/s, f Hz being the frequency of interest.

2.2 Coincidence frequency f_c

The coincidence frequency f_c is the frequency where $\nu = c$, c is the speed of the sound in the air.

$$f_c = \frac{c^2}{2\pi}\sqrt{\frac{\mu}{B}} \tag{4}$$

The important characteristic of the coincidence frequency f_c is :

- Below f_c the panel is omnidirectional
- Above f_c, beaming occurs. Not as pistonic speaker but lobes appear reducing the emission in some directions.

2.3 Efficiency

For the efficiency the literature like Kerem Ege's thesis [2] or the patent Heron's patent WO1992003024A1 [3] shows it is related to the Young modulus E of the material and its density ρ independently of the thickness through the parameter R.

$$R = E/\rho^3 \tag{5}$$

The Heron's patent [3] works with a parameter T

$$T = B/\mu^3 \tag{6}$$

R and T are independent of the thickness of the material.

$$T = R/12 \tag{7}$$

2.4 Mechanical impedance Z_m

The mechanical impedance relates forces with velocities acting on a mechanical system (from Wikipedia Mechanical impedance)

$$F(\omega) = Z_m(\omega).v(\omega) \tag{8}$$

Where, F is the force vector, v is the velocity vector, Z_m is the impedance matrix and ω is the angular frequency.

For an infinite plate driven in one point (see [4] or [5]):

$$Z_m = 8\sqrt{B\mu} \tag{9}$$

The theory predicts a first order low pass filter between the voice coil mass m_c and the panel mechanical impedance Z_m leading to a reduction of the sound level above the cut off frequency f_{high}.

$$f_{high} = \frac{Z_m}{2\pi m_c} \tag{10}$$

3 Material chart $B = f(\mu)$: the DML magic triangle?

See figure 1

The first possibility of plot is based on the standard representation where the material are shown in a Young Modulus E versus density ρ plot.

Here the idea is to plot each material in a graph stiffness B versus areal density μ.

There are at least 2 advantages for the B, μ chart compare to the E, ρ one :

- B and μ are the quantities that drive the basic formulas. Each other quantity related to B and μ thanks to product, power can be plotted as a straight line in a $log(B)$, $log(\mu)$ graph.
- Plates of same material but different thickness have different points

Three quantities can be plotted according to one or several criteria for each :

- f_c : the coincidence frequency. 2 values are shown. 5kHz and 20kHz. The role of the second one is to show in which direction in the plot the coincidence frequency increases.
- T : the target is to be above 10, if possible close to 100. See the Heron's patent [3].
- Z_m : this the less known quantity. One may imagine that a maximum value is needed to reach the highest frequencies targeted. As the exciter/panel interface is not a point, the mechanical impedance above is probably not the right one. This is something to study more deeply.

Those criteria according to the targeted values are straight lines in the graph.

Considering the directions those quantities change, a material for the panel inside the triangle defined by the 3 plain lines (see figure below, the purple dash lines) might have a coincidence frequency higher than 5kHz, a not to bad efficiency (T>10), a not too bad high frequency extension... to be checked against tests...

Three criteria being based on 2 variables : an additional degree of freedom should be added to satisfy all the target (coincidence frequency, efficiency, highest frequencies)...

A fourth criteria is on the graph to give a limit to the surface of the panel to reach the lowest frequencies. This criteria is the product area, 1st mode in m²Hz. For example, if the target is to reach 100Hz with a 0.8m² panel, the product $A.f_0$ is 80m²Hz. The source of that is the 1st mode :

$$A.f_0 = \pi \sqrt{\frac{B}{\mu}} \tag{11}$$

Which is true for a square plate, an approximation if it is a rectangle.

Being lead by $\frac{B}{\mu}$ while the coincidence frequency is led by $\frac{\mu}{B}$, this criteria is satisfied when the coincidence frequency criteria is satisfied. If a smaller area is targeted, this is no more true.
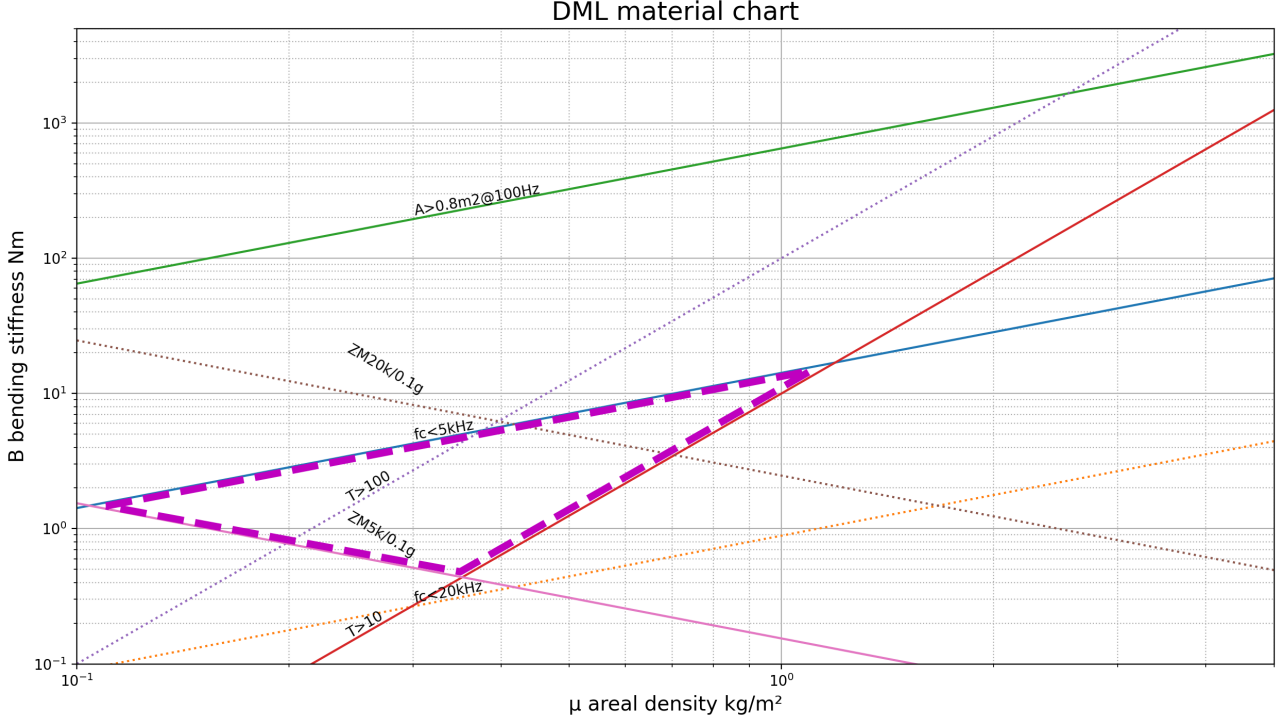

Figure 1: DML material chart

4   Material chart $B = f(\mu)$: material mapping

See figure 2

In each document about DML I read, I have collected the material, the B, μ characteristics. Unfortunately, I haven't kept notes of the source for all. Nevertheless this gives a beginning of DML material data base.

Values were added by some personal tests. Here the method to approach the value of the stiffness has to be improved. The measure of the wave speed is a possibility. This is beyond the target of the current paper which is to make an introduction to the DML material graph.

Some other values are assumptions like for the Tectonic material based on information gathered from Tectonic publications (papers, specifications, videos)... and a large spoon of assumptions!

Surprisingly, most of the materials encountered in the readings are out of the triangle. This is perhaps not so surprising considering the target areas suggested after are rather small.

EPS and poplar (characteristics for them to be checked) have the expected position according the DML builders feedback.

5   Material chart $\frac{B}{\mu} = f(T)$ with f_c and $A.f_0$ scales

See figure 3

An other graph is possible based on $\frac{B}{\mu}$ versus $\frac{B}{\mu^3}$.

In this graph, the "isof_c" and "iso$T$" become horizontal and vertical lines. The reading might be a bit simplified.
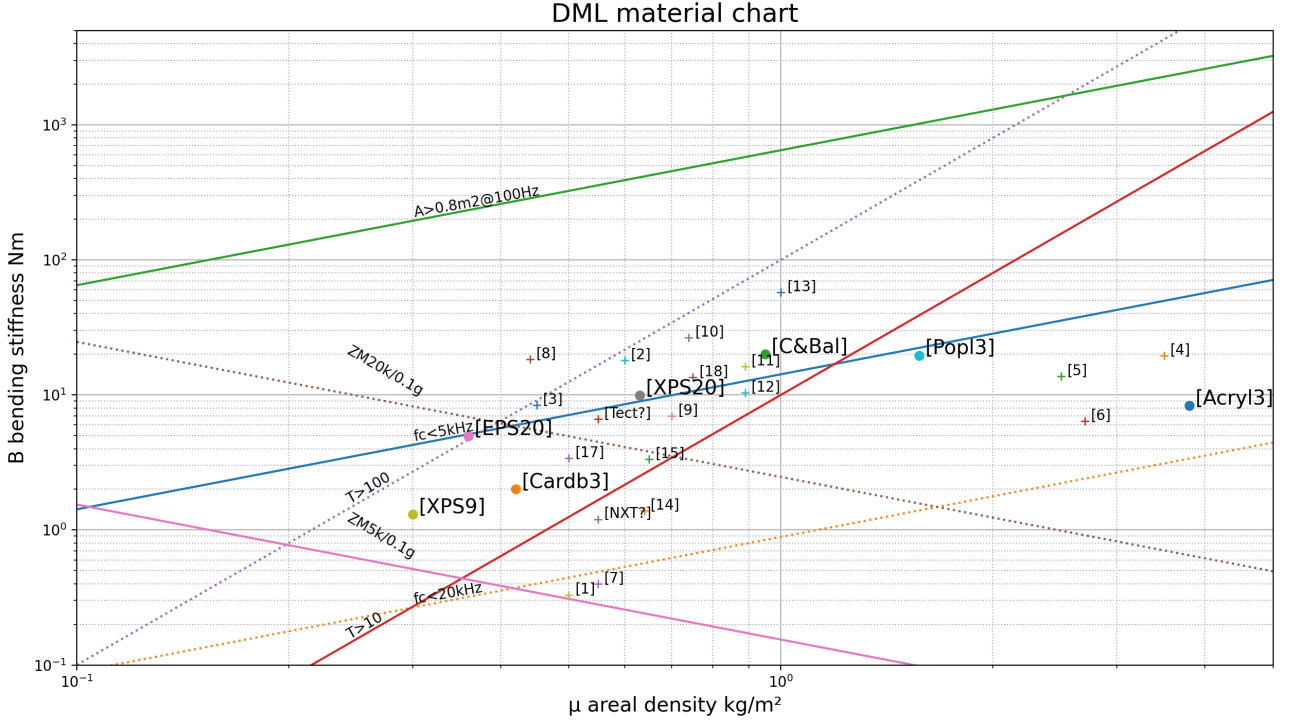
Figure 2: DML material chart

The iso"Z_m" remains an oblique straight line.

Two additional vertical scales are provided to shown 2 quantities directly linked to $\frac{B}{\mu}$:

- f_c the coincidence frequency
- $A.f_0$ the surface first mode product in Hz.m²

23 materials are listed :

- 9 are below the T=10 lines showing the materail with a low or even very low efficiency due mainly to their high density
    - Foamboard, polycarbonate, acrylic, plywood (even poplar), aluminum
- 8 are below 5kz in coincidence frequency probably for a too high stiffness compare to their density.
    - Balsa (to be checked) and mainly composite material. Composite materials have the property to be light and stiff, too stiff for the DML application.
- 7 into the magic triangle
    - EPS, cardboard, Tectonic composite, composites like glass fiber on Nomex or polycarbonate core, carbon on Rohacell.

The point XPS9 is in the chart as bad exemple. It is the material of the second DML I built which was a failure. It never got high frequencies which is not surprising seeing its position in the chart.

6 Material table

Here is the table of materials used in this script.

One comment on how the Tectonic material parameters were evaluated :

- From the Tectonic DML500 spec sheet in page 2, the hemispherical contour plot and the polar plots show the beam effect starts around 5 to 6kHz. This gives a $\frac{B}{\mu}$ of 12 ($f_c = 5500$Hz)
- The same specification gives an efficiency of 91dB which following the estimation of the efficiency is a $\frac{B}{\mu^3}$ of 40. See DML efficiency with all the caution mentioned in the document.
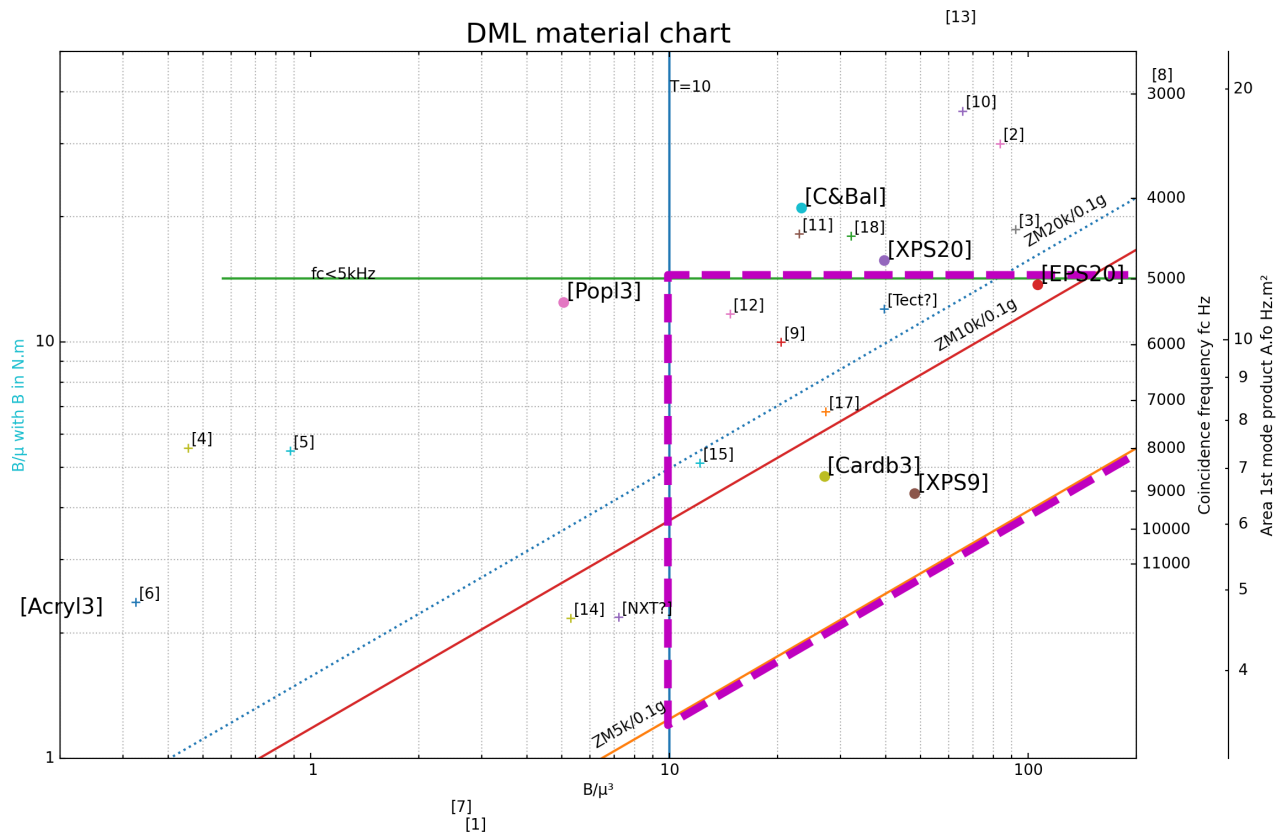
$$Eff = 83 + 5.log(T) \tag{12}$$

Eff in dB

Figure 3: DML material chart

So a areal mass of 0.55kg/m² and a stiffness of 6.6Nm. Does it make sens? It is the point.

#	μ kg/m²	B Nm	material	comment
[NXT?]	0.55	1.2	NXT	estimation of NXT material
[1]	0.5	0.33	unknown2	
[2]	0.6	18.0	unknown4	
[3]	0.45	8.4	balsa 3mm	
[4]	3.5	19.5	plywood std 5mm	
[5]	2.5	13.7	plywood light 5mm	
[6]	2.7	6.4	aluminium 1mm	
[7]	0.55	0.4	foamboard	
[8]	0.44	18.4	paper nomex 5mm	Podium?
[9]	0.7	7.0	GF nomex 3mm	Loudspeaker-and-headphone-handbook-third-edition
[10]	0.74	26.6	unknown3	https://ir.nctu.edu.tw/bitstream/11536/27128/1/
[11]	0.89	16.2	5mm polycarb honeycomb thermoplastic skin?	5mm honeycombe like polycarbonate core with thermoplastic skin, http://www.ipcsit.com/vol49/018-ICITM2012-DE0011.pBF
[12]	0.89	10.4	glass on polycarb. core	https://patentimages.storage.googleapis.com/84/f
[13]	1.0	57.6	carbon on alu core	
[14]	0.64	1.39	polycarb. on polycarb. core	
[15]	0.65	3.33	Carbone on Rohacell	
[Tect?]	0.55	6.6	Tectonic BmL500	Extrapolated from Tectonic BmL100/500 tech specs

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#	µ kg/m²	B Nm	material	comment
[17]	0.5	3.4	Polyester imp. paper honeycomb	Bx=4.23, By=2.63Nm, Allicante University https://www.researchgate.net/publication/223223 exciter_distributed_mode_loudspeakers
[18]	0.75	13.5	GF on alu honeycomb 4mm	high-performance-loudspeakers-optimising-high-fidelity-loudspeaker-systems-7
[EPS20]	0.36	4.95	EPS LM 20mm	LM=LeroyMerlin (french DIY store)
[XPS20]	0.63	9.9	XPS LM 20mm	LM=LeroyMerlin (french DIY store)
[XPS9]	0.3	1.3	XPS Diall 9mm	Diall=BricoDepot/Castorama brand (french DIY store)
[Popl3]	1.57	19.6	Poplar plywood PWD 3mm	
[Acryl3]	3.8	8.3	Acrylic 3mm	
[Cardb3]	0.42	2.0	Cardboard E flute	
[C&Bal]	0.95	20.0	CF/balsa	Veleric

7 To targets?

See figure 4

The 3 criteria listed are not independent so for each application, 2 can be prioritized, the third one will result.

7.1 Target for a home audio application

For a home audio application, the proposal is to choose the coincidence frequency f_c and the high cut off frequency f_{high} in order to offer the best frequency range with a wide dispersion.

- $6500\text{Hz} < f_c < 7500\text{Hz}$
- $15\text{kHz} < f_{high} < 20\text{kHz}$

See blue area in plot 4

7.2 Target for a PA application

Here the proposal is to search for a high T for the efficiency and a high enough cut off frequency. As the results from EPS shown a difficulty to go to the high frequencies, the target is set a bit under with unfortunately a loss of efficiency.

- $80 < T < 110$
- $f_{high} > 20\text{kHz}$

See green area in plot 4

8 Membrane design / tuning

We see from the chart that there is few chance to have the panel right in the targeted area by buying some raw material in a DIY store... Sad!

8.1 Plain material

See figure 5

We have seen that the T is independent of the thickness. So any plain material out of the target but on a vertical going through the target should meet it by adjusting the thickness.

In the list here, only XPS meets this condition.

Let's call h_0 and μ_0 the thickness and the areal density of the known material (in the exemple the XPS 20mm)
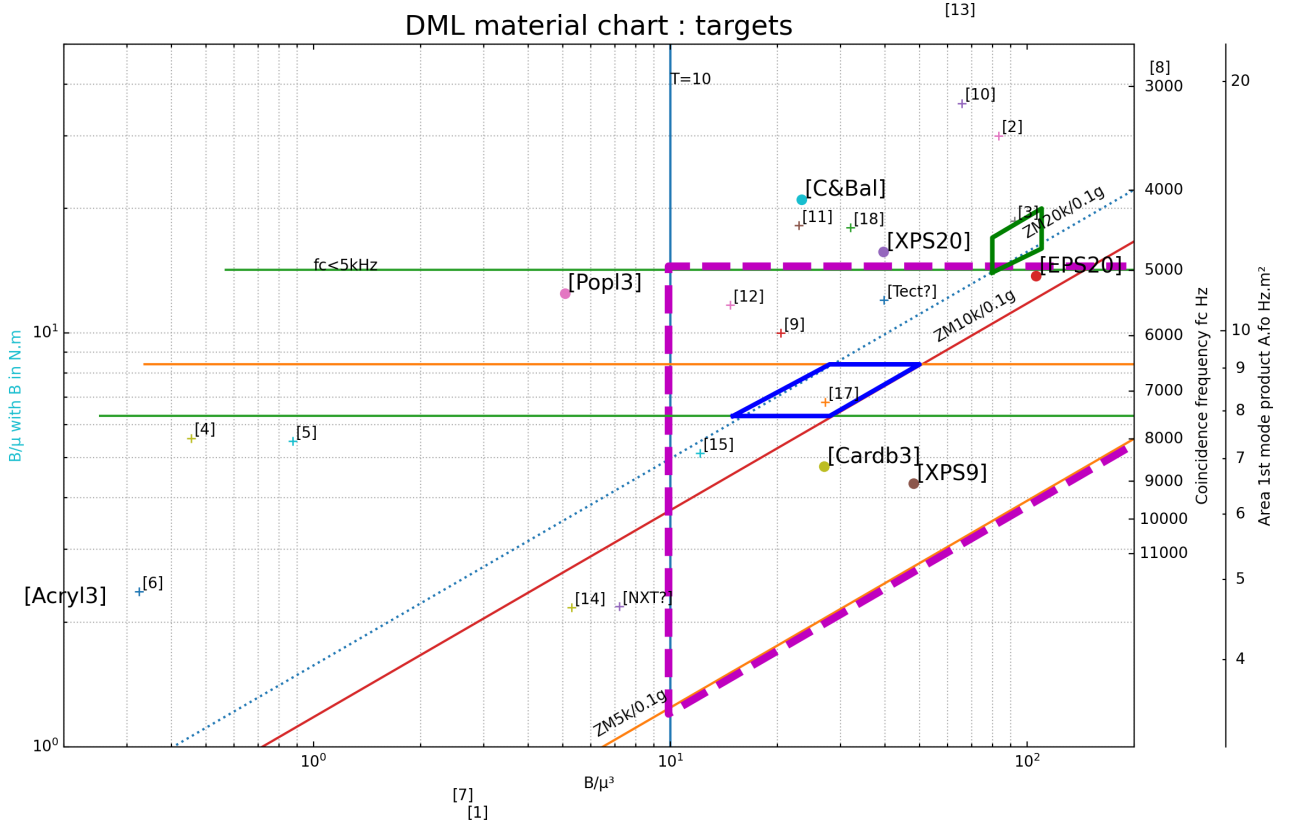
Figure 4: DML material chart : targets

and $\frac{B}{\mu}$ and T the target.

$$h_{target} = \frac{h_0}{\mu_0} \cdot \sqrt{\frac{B}{\mu} \cdot \frac{1}{T}}$$

In the chart, different thickness of XPS are shown.

8.2 Sandwich material

For sandwich material (ie composite or coating plain material), the thickness of the core might be adjusted.

This section need some input.

9 For the wood lovers

See figure 6

Plywood and for example poplar plywood has been identified as a good option by the DML builders.

Unfortunately, the plywood won't move to the right of the chart for a better efficiency but there might a possibility of improvement by reducing the thickness. This should increase the coincidence frequency while keeping some margin for the highest frequency (keeping it above 20kHz)

10 Conclusion

The idea of the material plot for DML based on the plate vibration theory was detailed in this paper. Hopefully it makes a link between the DML theory and DML builder experience. If not some changes will be needed... in this paper of course.

A first classification of the material that fits with one can read on the DIY forums was done.

Targets for home application and for PA application are also suggested.
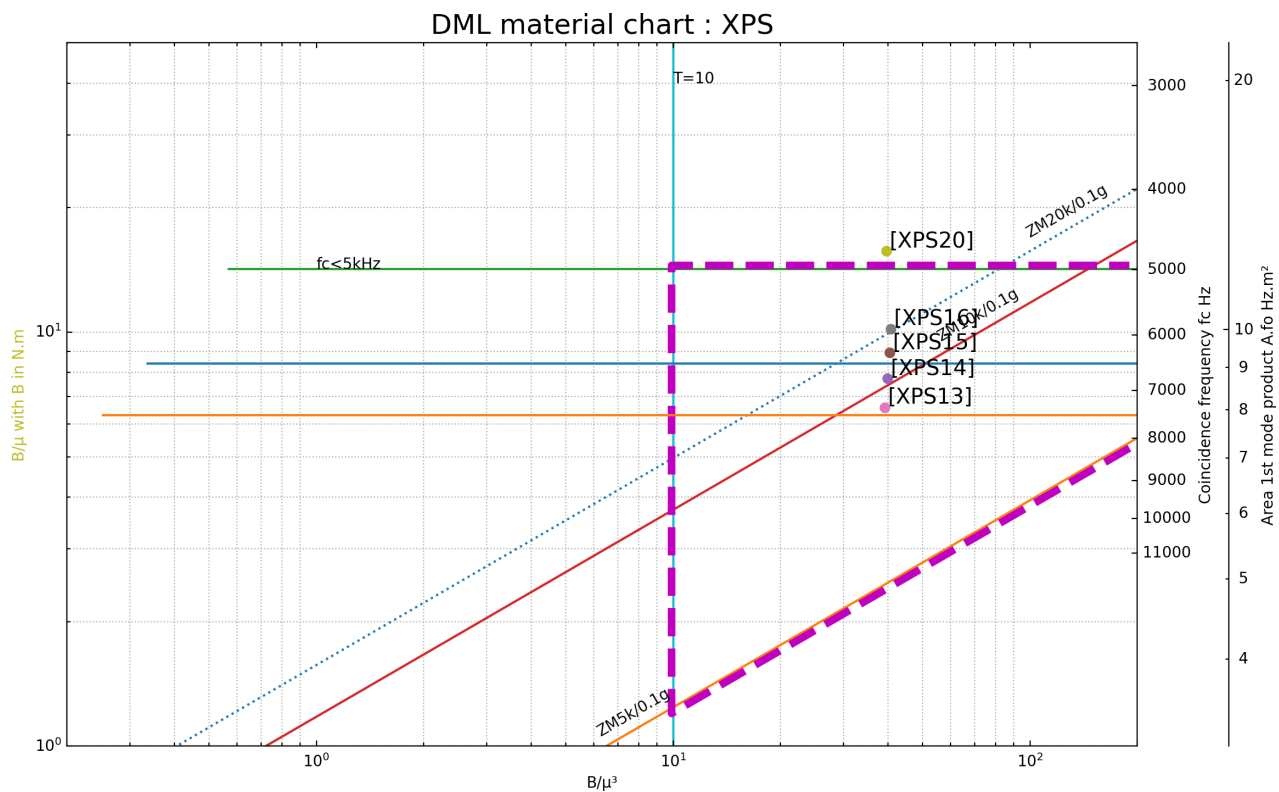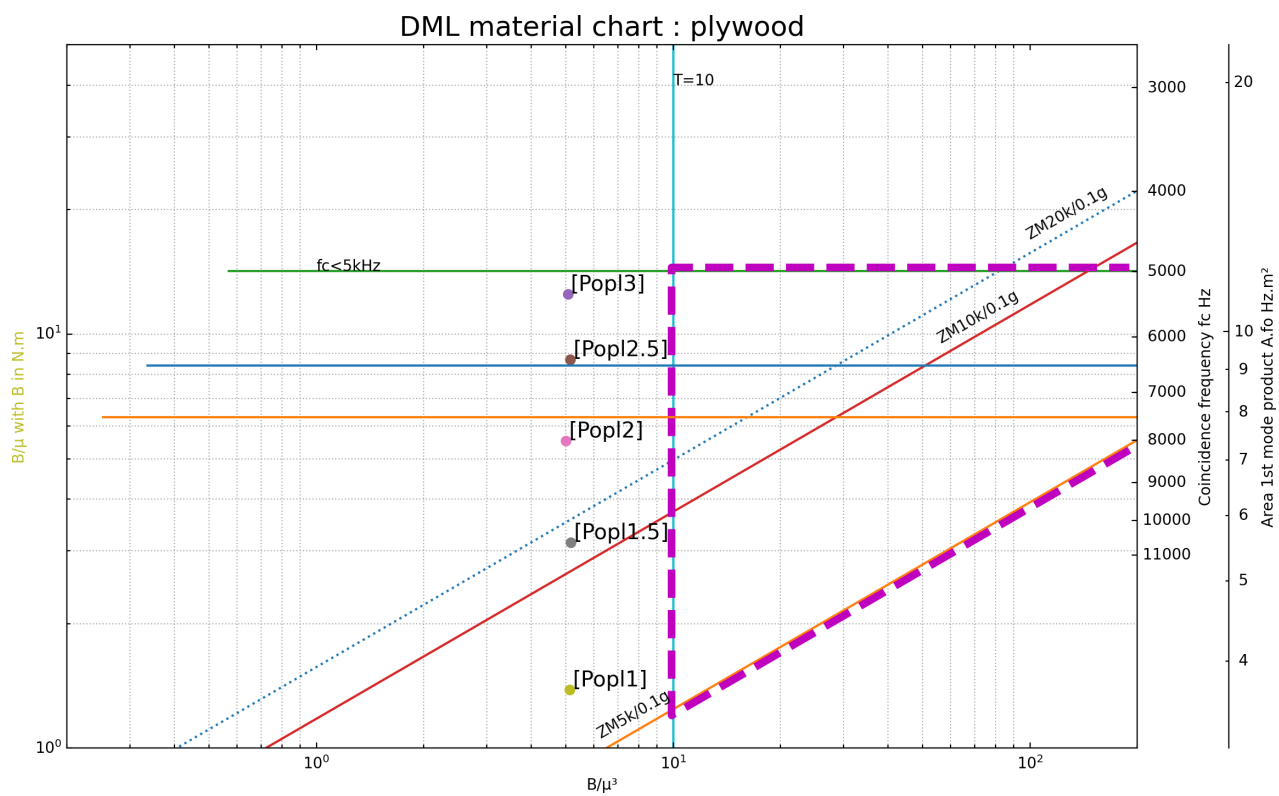
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Figure 5: DML material plain material tuning

Figure 6: DML material plain material tuning

Methods for membrane tuning (plain material) or design (sandwich) are also proposed

For now it is more the principle of the use of the chart and the equations below that are highlighted, more than the values of stiffness for material like XPS or plywood. In addition difference in XPS and plywood may occur depending of the sourcing, the country.

The next steps are :

- Check the materials data and the sources
- Improve the method to measure the bending stiffness of a given material

And the most important : do the materials fitting to the target areas work?

11 Python script code - skip this if no interest for the code!

11.1 Import modules

```python
import os # for py2pdf
import subprocess # for py2pdf with bash with alias
import libpy2pdf as p2p
from mpl_toolkits.axisartist.parasite_axes import HostAxes, ParasiteAxes
import matplotlib.pyplot as plt
import matplotlib.ticker as mtick
import numpy as np
```

11.2 Functions

```python
def fcoincidence(X):
    # returns the coincidence frequency with X = B/mu
    fc = 344**2/2/np.pi/np.sqrt(X)
    return fc


def BFcritic(fc, mu):
    # returns the stiffness B for a targeted fc according mu
    BFcritic = mu * 344.**4 / (2*3.14*fc)**2
    return BFcritic


def BFlow(flow, A, mu):
    # returns the stiffness B for a targeted panel surface A and a 1st mode according to mu
    BFlow = mu * (A*flow/np.pi)**2
    return BFlow


def BT(T, mu):
    # returns the stiffness B for a targeted efficiency coeff T according to mu
    BT = T * mu**3
    return BT


def BZm(Zm, mu):
    # returns the stiffness B for a targeted mechanical impedance according to mu
    BZm = ((Zm/8)**2)/mu
    return BZm
```

11.3 Prepare py2pBF

```python
# lines to be included for py2pdf export
scriptname = os.path.basename(__file__).split('.')[0] # get this script file name without extension
p2p.outputdir() # create the directory to store the output
```

11.4 Tables of parameter

```python
# list of μ to create the graph
mu_list = np.array([0.1, 0.125, 0.160, 0.2, 0.25, 0.32, 0.4, 0.5, 0.63, 0.8,
          1., 1.25, 2., 3.2, 4., 5.])
```

```python
# long table of μ and B for different materials. Format (#, material, μ kg/m², B Nm, comment)
material_list1 = [('NXT?', 'NXT', 0.55, 1.2, 'estimation of NXT material'),
                  ('1', 'unknown2', 0.5, 0.33, ''),
                  ('2', 'unknown4', 0.6, 18., ''),
                  ('3', 'balsa 3mm', 0.45, 8.4,''),
                  ('4','plywood std 5mm', 3.5, 19.5,''),
                  ('5', 'plywood light 5mm', 2.5, 13.7,''),
                  ('6', 'aluminium 1mm', 2.7, 6.4,''),
                  ('7', 'foamboard', 0.55, 0.4, ''),
                  ('8', 'paper nomex 5mm', 0.44, 18.4, 'Podium?'),
                  ('9', 'GF nomex 3mm', 0.7, 7., 'Loudspeaker-and-headphone-handbook-third-edition'),
                  ('10', 'unknown3', 0.74, 26.6, 'https://ir.nctu.edu.tw/bitstream/11536/27128/1/000188
                  ('11', '5mm polycarb honeycomb thermoplastic skin?', 0.89, 16.2, '5mm honeycombe like
                  ('12', 'glass on polycarb. core', 0.89, 10.4, 'https://patentimages.storage.googleapi
                  ('13', 'carbon on alu core', 1., 57.6, ''),
                  ('14', 'polycarb. on polycarb. core', 0.64, 1.39, ''),
                  ('15', 'Carbone on Rohacell', 0.65, 3.33, ''),
                  ('Tect?', 'Tectonic BmL500', 0.55, 6.6, 'Extrapolated from Tectonic BmL100/500 tech s
                  ('17', 'Polyester imp. paper honeycomb', 0.5, 3.4, 'Bx=4.23, By=2.63Nm, Allicante Uni
                  ('18', 'GF on alu honeycomb 4mm', 0.75, 13.5, 'high-performance-loudspeakers-optimisi
                  ]
# short table of μ and D for different materials. Format (#, material, μ kg/m², B Nm, comment)
material_list2 = [('EPS20', 'EPS LM 20mm', 0.36, 4.95, 'LM=LeroyMerlin (french DIY store)'),
                  ('XPS20', 'XPS LM 20mm', 0.63, 9.9, 'LM=LeroyMerlin (french DIY store)'),
                  ('XPS9', 'XPS Diall 9mm', 0.3, 1.3, 'Diall=BricoDepot/Castorama brand (french DIY sto
                  ('Popl3', 'Poplar plywood PWD 3mm', 1.57, 19.6, ''),
                  ('Acryl3', 'Acrylic 3mm', 3.8, 8.3, ''),
                  ('Cardb3', 'Cardboard E flute', 0.42, 2., ''),
                  ('C&Bal', 'CF/balsa', 0.95, 20.,'Veleric')
                  ]
# short table of μ and D for different materials. Format (#, material, μ kg/m², B Nm, comment)
material_list3 = [('XPS14', 'XPS LM 14mm', 0.44, 3.4, ''),
                  ('XPS15', 'XPS LM 15mm', 0.47, 4.2, ''),
                  ('XPS13', 'XPS LM 13mm', 0.41, 2.7, ''),
                  ('XPS16', 'XPS LM 16mm', 0.50, 5.1, ''),
                  ('XPS20', 'XPS LM 20mm', 0.63, 9.9, 'LM=LeroyMerlin (french DIY store)'),
                  ]
# short table of μ and D for different materials. Format (#, material, μ kg/m², B Nm, comment)
material_list4 = [('Popl3', 'Poplar plywood PWD 3mm', 1.57, 19.6, ''),
                  ('Popl2.5', 'Poplar plywood PWD 2.5mm', 1.3, 11.3, ''),
                  ('Popl2', 'Poplar plywood PWD 2mm', 1.05, 5.8, ''),
                  ('Popl1.5', 'Poplar plywood PWD 1.5mm', 0.78, 2.45, ''),
                  ('Popl1', 'Poplar plywood PWD 1mm', 0.52, 0.72, ''),

                  ]
```

11.5 Graph preparation

```python
# Stiffness for different fc
BFcritic_5k = BFcritic(5000., mu_list)
BFcritic_6d5k = BFcritic(6500., mu_list)
BFcritic_7d5k = BFcritic(7500., mu_list)
BFcritic_20k = BFcritic(20000., mu_list)
# Prepare some arrays
F5k = 5000*np.ones(len(mu_list))
Af0_1 = 15*np.ones(len(mu_list))
F20k = 20000*np.ones(len(mu_list))
Af0_2 = 5*np.ones(len(mu_list))
# Stiffness for different couple of 1st mode, surface
BFlow_05m2 = BFlow(40, 0.5, mu_list) # 40Hz, 0.5m²
BFlow_08m2 = BFlow(100, 0.8, mu_list) # 100Hz, 0.8m²
```

```python
BFlow_1m2 = BFlow(100, 1., mu_list) # 100Hz, 1m²
# Stiffness for different efficiency coeff T
BT10 = BT(10., mu_list) # T=10 (minimum)
BT100 = BT(100, mu_list) # T=100 (target)
# Stiffness for a given Zm
mms = 0.0001 # exciter voice coil mass in kg
BZ20k = BZm(2*np.pi*mms*20000, mu_list)
BZ15k = BZm(2*np.pi*mms*15000, mu_list)
BZ5k = BZm(2*np.pi*mms*5000, mu_list)
```

11.6   Chart 1 and 2 B=f(µ)

```python
# graph 1 & 2 -------------------------------------------------------------
for i in [0, 1]: # 0 is chart without materials, 1 with materials
    fig = plt.figure(figsize=(15, 8)) # create the figure
    plt.loglog(mu_list, BFcritic_5k) # plot line fc=5k
    plt.loglog(mu_list, BFcritic_20k, ':') # plot line fc=20k
    plt.loglog(mu_list, BFlow_08m2) # plot line Af0=80
    plt.loglog(mu_list, BT10) # plot line T=10
    plt.loglog(mu_list, BT100, ':') # plot line T=100
    plt.loglog(mu_list, BZ20k, ':') # plot Zm=20k,0.1g
    plt.loglog(mu_list, BZ5k) # plot Zm=5k,0.1g
    ang1 = 30 # for text annot.
    ang2 = ang1/3. # for text annot.
    plt.text(0.3, BFcritic_5k[5], 'fc<5kHz', rotation=ang2) # line legend
    plt.text(0.3, BFcritic_20k[5], 'fc<20kHz', rotation=ang2) # line legend
    plt.text(0.3, BFlow_08m2[5], 'A>0.8m2@100Hz', rotation=ang2) # line legend
    plt.text(0.24, BT10[4], 'T>10', rotation=ang1) # line legend
    plt.text(0.24, BT100[4], 'T>100', rotation=ang1) # line legend
    plt.text(0.24, BZ20k[4], 'ZM20k/0.1g', rotation=-ang1) # line legend
    plt.text(0.24, BZ5k[4], 'ZM5k/0.1g', rotation=-ang1) # line legend
    plt.grid(which='major') # set grid
    plt.grid(which='minor', linestyle=':') # set grid
    plt.xlabel('µ areal density kg/m²', fontsize=14) # x axis label
    plt.ylabel('B bending stiffness Nm', fontsize=14) # y axis label
    plt.xlim(0.1, 5) # x span
    plt.ylim(0.1, 5000) # y span
    plt.title('DML material chart', fontsize=18) # title
    if i==0:
        plt.plot((.11, 1.1, .35, .11), (1.47, 14.7, .48, 1.47), 'm--', lw=5) # magic triangle
        # save figure
        fig.savefig("./py2pdf_files/DMLmat0.png", bbox_inches="tight", dpi = 200) # this is the key lin
    if i==1:
        logfile = "./py2pdf_files/DML_mat.txt" # define the logfile
        p2p.clearlog(logfile) # clear the logfile (in case script is ran several times)
        p2p.print_twice(logfile, '| # | µ kg/m² | B Nm | material | comment |') # markdown table 1st li
        p2p.print_twice(logfile, '|--|--|--|---|-----|')
        for mat in material_list1: # loop in mat list1
            index, material, mu, Bm, comment = mat
            plt.loglog(mu, Bm, '+') # plot material
            index = "["+index+"]"
            tableline = '| '+ index + ' | ' + str(mu) + ' | ' + str(Bm) + ' | ' + material + ' | ' + co
            # p2p.print_twice(logfile,index, mu, Bm, material, comment)
            p2p.print_twice(logfile,tableline)
            plt.text(mu*1.02, Bm*1.02, index, fontsize=10) # label in the chart

        for mat in material_list2: # loop in mat list2
            index, material, mu, Bm, comment = mat
            index = "["+index+"]"
            tableline = '| '+ index + ' | ' + str(mu) + ' | ' + str(Bm) + ' | ' + material + ' | ' + co
            # p2p.print_twice(logfile,index, mu, Bm, material, comment)
```

```
            p2p.print_twice(logfile,tableline)
            plt.loglog(mu, Bm, 'o')
            plt.text(mu*1.02, Bm*1.02, index, fontsize=14)
        plt.title('DML material chart', fontsize=18) # chart title
        ## save figure
        fig.savefig("./py2pdf_files/DMLmat1.png", bbox_inches="tight", dpi = 200) # this is the key lin
    plt.show()
```

11.7   Chart 3 to 6 B/μ=f(B/μ³)

```
# graph 3 to 6 --------------------------------------------------------------------
for i in [0, 1, 2, 3]: # 0 is material, 1 is with targets, 2 for XPS, 3 for plywood
    fig = plt.figure(figsize=(15, 8))
    host = fig.add_axes([0.15, 0.1, 0.65, 0.8], axes_class=HostAxes)
    par1 = ParasiteAxes(host, sharex=host)
    par2 = ParasiteAxes(host, sharex=host)
    host.parasites.append(par1)
    host.parasites.append(par2)
    host.axis["right"].set_visible(False)
    par1.axis["right"].set_visible(True)
    par1.axis["right"].major_ticklabels.set_visible(True)
    par1.axis["right"].label.set_visible(True)
    par2.axis["right2"] = par2.new_fixed_axis(loc="right", offset=(60, 0))
    fullgraph = True
    host.loglog(BZ20k/mu_list**3, BZ20k/mu_list, ':')
    host.loglog(BZ5k/mu_list**3, BZ5k/mu_list)
    host.loglog(BFcritic_5k/mu_list**3, BFcritic_5k/mu_list)
    host.loglog(BZ15k/mu_list**3, BZ15k/mu_list)
    if i==0 or i==1:
        if fullgraph:
            for mat in material_list1:
                index, material, mu, Bm, comment = mat
                index = "["+index+"]"
                host.loglog(Bm/mu**3, Bm/mu, '+')
                host.text(Bm/mu**3*1.02, Bm/mu*1.02, index, fontsize=10)
        for mat in material_list2:
            index, material, mu, Bm, comment = mat
            index = "["+index+"]"
            p1, = host.loglog(Bm/mu**3, Bm/mu, 'o')
            host.text(Bm/mu**3*1.02, Bm/mu*1.02, index, fontsize=14)
    if i==2:
        for mat in material_list3:
            index, material, mu, Bm, comment = mat
            index = "["+index+"]"
            p1, = host.loglog(Bm/mu**3, Bm/mu, 'o')
            host.text(Bm/mu**3*1.02, Bm/mu*1.02, index, fontsize=14)
    if i==3:
        for mat in material_list4:
            index, material, mu, Bm, comment = mat
            index = "["+index+"]"
            p1, = host.loglog(Bm/mu**3, Bm/mu, 'o')
            host.text(Bm/mu**3*1.02, Bm/mu*1.02, index, fontsize=14)

    plt.grid(which='major')
    plt.grid(which='minor', linestyle=':')
    ymin = 1
    ymax = 50
    host.set_ylim(ymin, ymax)
    host.set_xlim(0.2, 200)
    par1.set_ylim(fcoincidence(ymin), fcoincidence(ymax))
    par2.set_ylim(3.14*ymin**.5, 3.14*ymax**.5)
```

```python
    par1.set_yscale('log')
    par2.set_yscale('log')
    host.yaxis.set_major_formatter(mtick.FormatStrFormatter('%2d'))
    host.xaxis.set_major_formatter(mtick.FormatStrFormatter('%2d'))
    par1.yaxis.set_major_locator(mtick.FixedLocator(np.arange(3000, 12000, 1000)))
    par1.yaxis.set_major_formatter(mtick.FormatStrFormatter('%5d'))
    par2.yaxis.set_minor_formatter(mtick.FormatStrFormatter('%2d'))
    par2.yaxis.set_major_formatter(mtick.FormatStrFormatter('%2d'))
    n = 6
    plt.text(BZ20k[n]/mu_list[n]**3, 1.1*BZ20k[n]/mu_list[n], 'ZM20k/0.1g', rotation=ang1)
    plt.text(BZ5k[n]/mu_list[n]**3, 1.1*BZ5k[n]/mu_list[n], 'ZM5k/0.1g', rotation=ang1)
    plt.text(BZ15k[n]/mu_list[n]**3, 1.1*BZ15k[n]/mu_list[n], 'ZM10k/0.1g', rotation=ang1)
    plt.text(1, BFcritic_5k[5]/mu_list[5], 'fc<5kHz')
    plt.text(10, 40, 'T=10')
    plt.plot((10,10), (ymin,ymax))
    host.set_xlabel('B/µ³', fontsize=16)
    host.set_ylabel('B/µ with B in N.m', fontsize=16)
    par1.set_ylabel("Coincidence frequency fc Hz", fontsize=14)
    par2.set_ylabel("Area 1st mode product A.fo Hz.m²", fontsize=14)
    plt.plot((190., 9.9, 9.9, 190.), (5.25, 1.2, 14.5, 14.5), 'm--', lw=5)
    host.axis["left"].label.set_color(p1.get_color())
    if i==0:
        plt.title('DML material chart', fontsize=18)
        # save figure
        fig.savefig("./py2pdf_files/DMLmat2.png", bbox_inches="tight", dpi = 200) # this is the key lin
    if i==1:
        host.loglog(BFcritic_6d5k/mu_list**3, BFcritic_6d5k/mu_list)
        host.loglog(BFcritic_7d5k/mu_list**3, BFcritic_7d5k/mu_list)
        plt.plot((15., 28., 50., 28., 15.), (6.3, 6.3, 8.4, 8.4, 6.3), 'b', lw=3)
        plt.plot((80., 110., 110., 80., 80.), (14., 16., 20., 17., 14.), 'g', lw=3)
        plt.title('DML material chart : targets', fontsize=18)
# save figure
        fig.savefig("./py2pdf_files/DMLmat3.png", bbox_inches="tight", dpi = 200) # this is the key lin
    if i==2:
        host.loglog(BFcritic_6d5k/mu_list**3, BFcritic_6d5k/mu_list)
        host.loglog(BFcritic_7d5k/mu_list**3, BFcritic_7d5k/mu_list)
        # plt.plot((15., 28., 50., 28., 15.), (6.3, 6.3, 8.4, 8.4, 6.3), 'b', lw=3)
        # plt.plot((80., 110., 110., 80., 80.), (14., 16., 20., 17., 14.), 'g', lw=3)
        plt.title('DML material chart : XPS', fontsize=18)
# save figure
        fig.savefig("./py2pdf_files/DMLmat4.png", bbox_inches="tight", dpi = 200) # this is the key lin
    if i==3:
        host.loglog(BFcritic_6d5k/mu_list**3, BFcritic_6d5k/mu_list)
        host.loglog(BFcritic_7d5k/mu_list**3, BFcritic_7d5k/mu_list)
        # plt.plot((15., 28., 50., 28., 15.), (6.3, 6.3, 8.4, 8.4, 6.3), 'b', lw=3)
        # plt.plot((80., 110., 110., 80., 80.), (14., 16., 20., 17., 14.), 'g', lw=3)
        plt.title('DML material chart : plywood', fontsize=18)
# save figure
        fig.savefig("./py2pdf_files/DMLmat5.png", bbox_inches="tight", dpi = 200) # this is the key lin

    plt.show()
```

11.8   py2pdf

```python
print("start py2pdf")
cmd = "py2pdf " + scriptname # alias
subprocess.call(['/bin/bash', '-i', '-c', cmd]) # to launch the bash file (alias)
```

References

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