QCM cavity power vs. field setpoint measurement

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Matt proposed to measure the forward and reflected power of the QCM cavities as a function of G_{set} to rule out the unlikely possibility that the Wang effect [1, 2] is caused by a nonlinearity in the field probe. Having done the measurement[1], I am starting to believe that this is actually the culprit. Anyone you ask will dismiss the issue mumbling something about relativity, but until someone shows me an error in my simulation, I'll keep trusting the numerical results, which show that the 2-cell energy gain has to be a linear function of the field amplitude despite this being counterintuitive.

1 Idea

What we are trying to explain is a nonlinear dependency between particle energy gain and 2-cell field amplitude, which has been observed experimentally at the UITF. The idea of this measurement is that in the case of strong overcoupling, field-dependent variations of Q_0 should not affect the relationship between incident power P_{forward} and field amplitude A so that $A \propto \sqrt{P}$ [3].

By the way, seeing as I don't like how the quantity G_{set} is commonly assigned a meaning it doesn't have, I'm going to treat it as unitless from now on.

2 Measurement

Figure 1 shows the result of the measurement for the 7-cell cavity. It behaves as expected.

Figure 2 shows what it looks like for the 2-cell cavity. The curve has a funny shape with both a left-handed and a right-handed curvature. Whether this behavior is real physics I don't understand or some deficiency of the coupler or field probe is not obvious to me. However, let's play around for a second by assuming the field is actually proportional to the root of the power and therefore depends on G_{set} in the depicted way. We can then transform the x axis of Yan's energy gain measurement to a quantity that we believe is

[1] Yan and I have independently measured these curves with similar results.

proportional to the field based on the RF power. As long as we have no idea what the underlying reason for the dependency is, we lack a decent analytical function describing it, so the simplest thing to do to get the numbers is a cubic spline interpolation function $\mathcal{G}$. Yan's data are shown in Fig. 3 with both representations. The transformation appears to sort of make the curvature go away, though the linearity is still not optimal and the y-axis intercept is not compatible with the gun energy. There are a variety of possible reasons for this, including but not limited to spectrometer calibration/hysteresis in Yan's data and systematic issues in the power measurement on my end. That being said, how much more linear the curve gets is intriguing.

I believe the result suggests that the beam-based energy gain measurement is largely correct and the 2-cell field probe is nonlinear. If this is true, the phases are most likely incorrect as well, making model-based predictions of the crest phase vs. field relationship a moo point[2]. For practical purposes, trusting the beam-based amplitude and phase calibration curve may be sufficient. However, the agreement with the numerical model will stay unsatisfactory, causing unnecessary inaccuracies in future simulations involving the QCM. I would therefore recommend finding out whether the behavior of the probe is in fact an error and, if so, fixing (linearizing) it.

[2] It's like a cow's opinion [4].

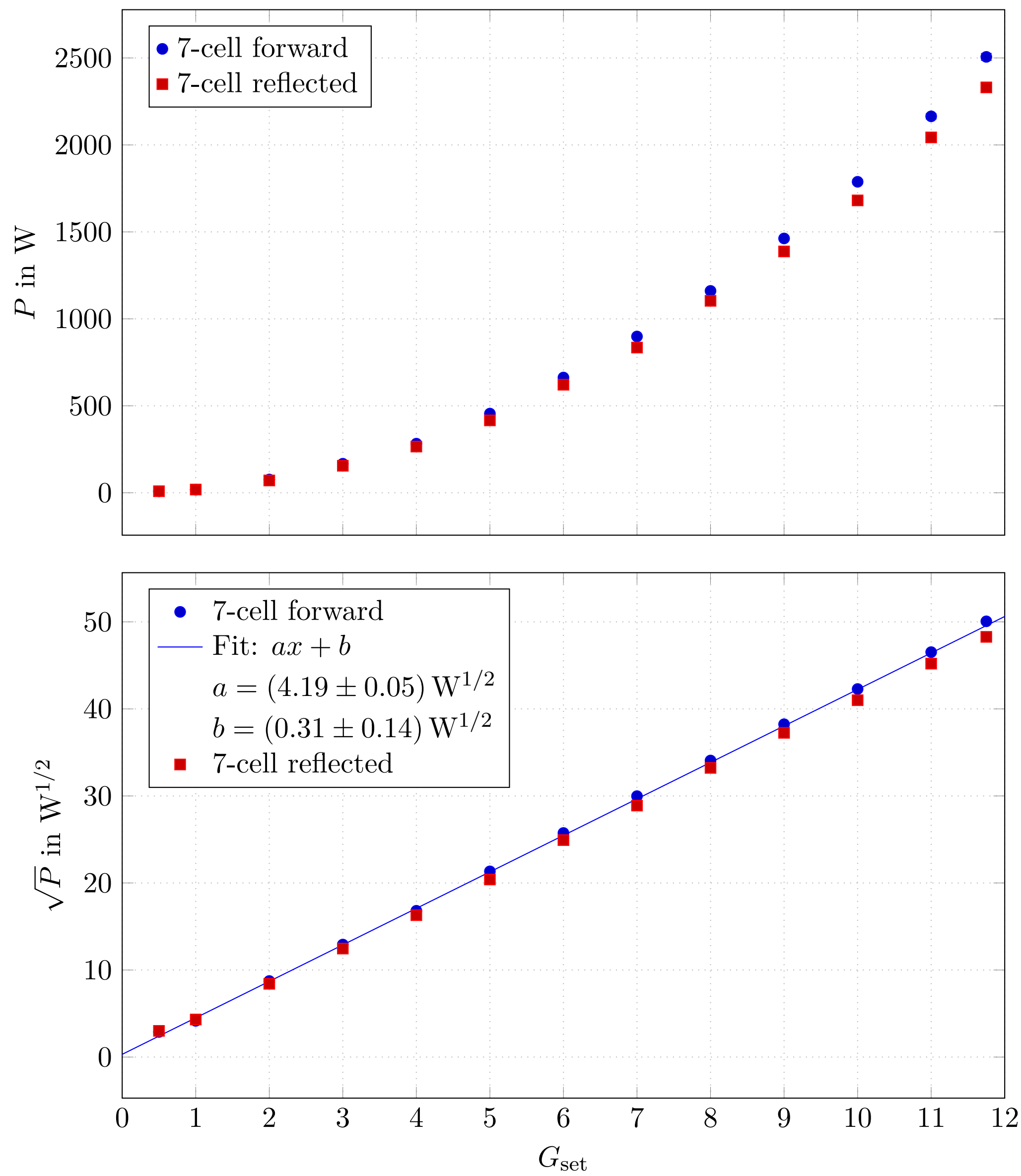

Figure 1: RF power scan for the 7-cell cavity. Each point represents the average of the respective EPICS channel over 60 seconds for noise suppression. The statistical error bars are too small to be visible. The offset of the power axis is close to zero, and the square root of the power does not exhibit any significant curvature.

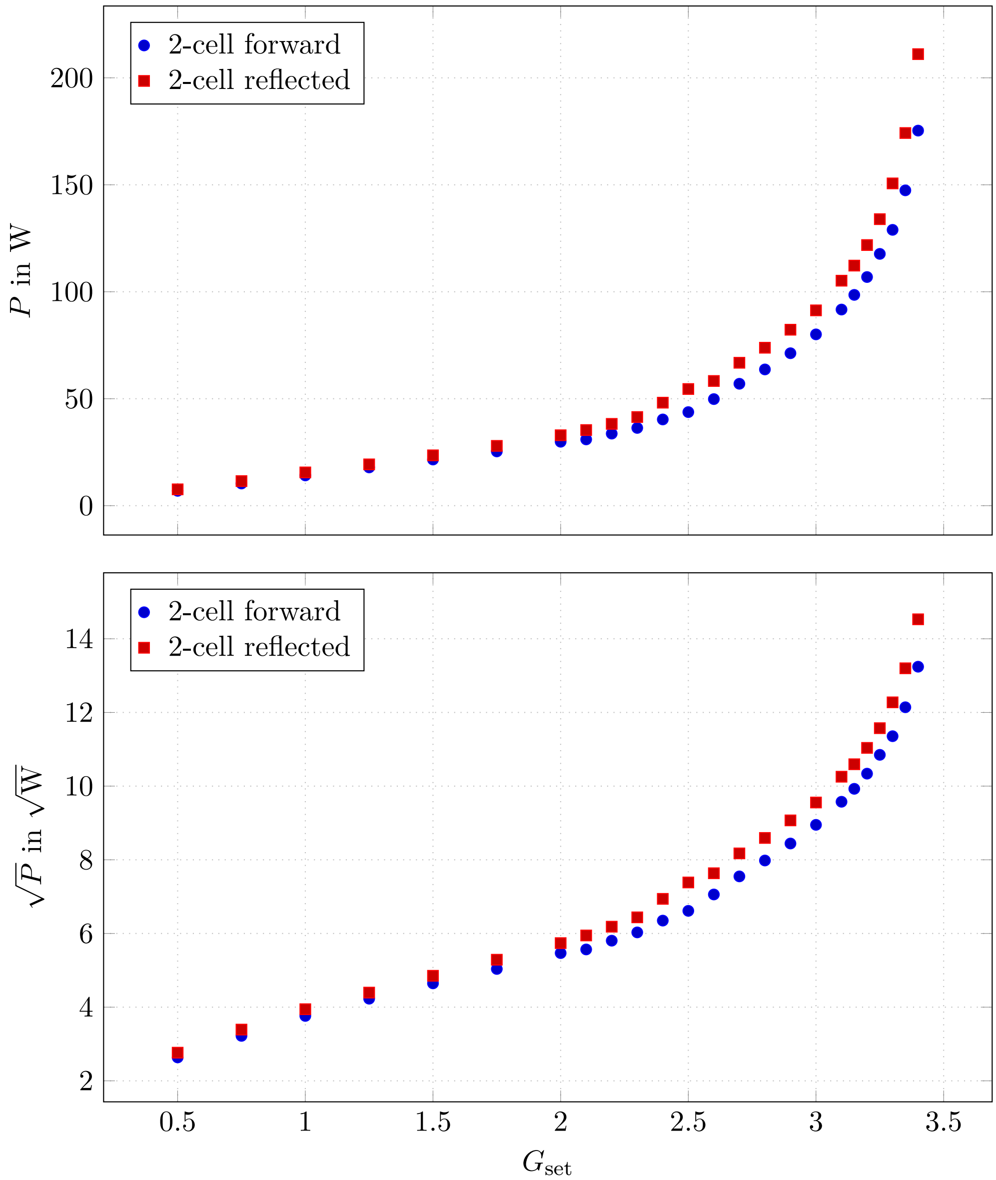

Figure 2: RF power scan for the 2-cell cavity. Each point represents the average of the respective EPICS channel over 300 seconds for noise suppression. The statistical error bars are too small to be visible. The offset is close to zero, but the shape of the curve in the vicinity of the origin cannot be determined accurately because the control loop appears to work only if $G_{\text{set}} > 0.5$. The square root of the power is a complicated function of the field setpoint. The reflected power also appears to be higher than the forward power. I'm not sure if there is any implication to this last statement other than hinting at a calibration error.

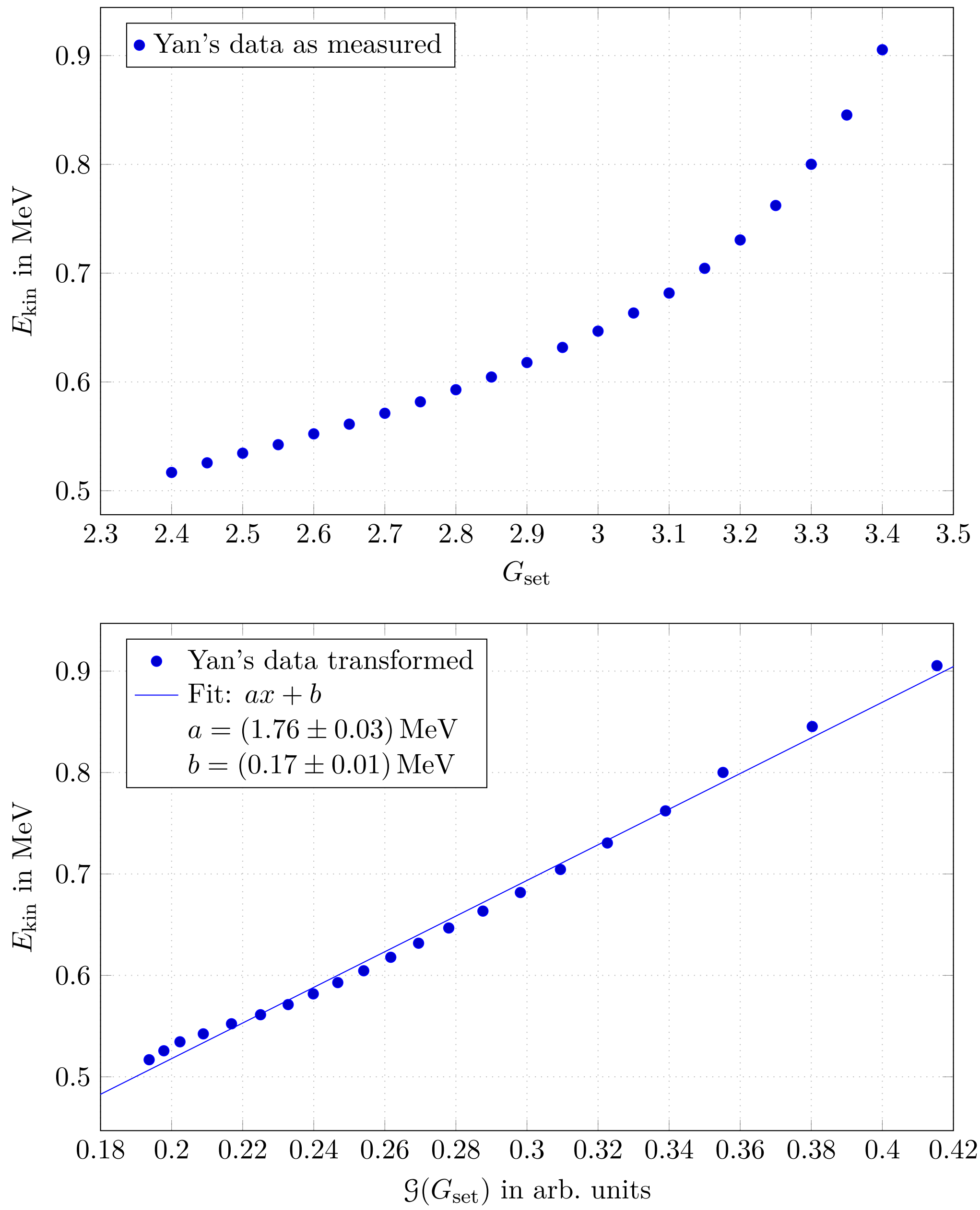

Figure 3: The measured energy gain is a somewhat linear function of $\mathcal{G}(G_{\mathrm{set}})$ if we close both eyes and pretend really hard. This resembles the behavior predicted by our tracking simulation.

References

[1] https://wiki.jlab.org/ciswiki/images/1/17/Max%27s_thoughts_on_booster_GSet_calibration.pdf

[2] https://wiki.jlab.org/ciswiki/images/6/6c/Max%27s_thoughts_on_impact_of_buncher_on_booster_GSet_calibration.pdf

[3] Tom Powers, Theory and Practice of Cavity RF Test Systems

[4] Friends, The one where Chandler doesn't like dogs