Design and simulation of a PI controller system with frequency response

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(Accepted for publication: December 21, 2016)

Abstract:

It is convenient to have a minimum number of parameters that are tuned to control a system. Proportional-integral-derivative (PID) controllers have this specification and are now daily used in a different field of application especially in industrial control system. To get the frequency response of such controller to any disturbance signal an appropriate design technique is needed. Here a PI controller system is implemented and simulated using NI Multisim (13.0) software. We study the frequency response of a PI controller. The results and calculations show that the designed PI controller has very fast (above than 10 kHz) response to any disturbance. We show a large match between the simulation and the experimental part. A bode plot that give us the frequency response of the system has been calculated and measured. The implemented work is important for many applications especially in the field of atomic force microscopy (AFM), scanning tunneling microscopy (STM) and other industrial control system that need fast control.

Keywords: *PID controller, PI, NI Multisim (version 13.0) software and frequency response.*

Introduction:

A proportional-integral-derivative (PID) controller is a control strategy that takes the form of feedback (Xue, Quan Chen, & Atherton , 2008) (Astrom, 2002). Feedback is a process of resulting mainly technical events so that it keeps the system in real time automatically closer to the desired state. PID is the most and the widely used controller system in industrial process due to the small number of key parameters that are needed to be tuned (Astrom, 2002). The proportional term (P part) determines the response of the present error, the integral term (I part) determines the response based on the accumulation of the past error and the derivative term determines the response based on the rate of the changing of the error. The aim of PID controller is ideally to make the error between the set point (reference input signal) and the output signal to zero. In practice this is not so easily. For this reason, the PID controller has to be tuned to a specified value depending on the application and the tuning of each term of the PID controller can be done by adjusting the gain of term itself. Today the most preferred type of PID controller is the proportional-integral (PI) type controller due to the fact that the derivative term provides some difficulties when handling with noisy signal. This controller is used in different fields of applications, such as atomic force microscopy (Sadiq, et al., 2011), Quadcopter controller (Hassan, Faiz, Faizan, & Kamran, 2013), and temperature controller (Kuo, 1997) (Zhuang & Atherton, 1993).

It is convenient to simulate any active element before realizing them experimentally. Some work presents the PID controllers by using operational amplifiers (Franco, 1997). In this work, a PI controller is implemented and simulated based on operational amplifiers. We show the match between the simulation and the experimental part. Furthermore, the bode plot (frequency response) of the system that depends on the gain factor of each terms of the PI controller type is demonstrated. This is of interest when working with a system that need fast response to any events.

Controller schemes and results

The work of PID is to make the signal error (difference between the set-point and the variable signal) as small as possible. The principle of PID controller mathematically can be described as (Basilio & Matos, 2002)

$$u(t) = K_p \left[e(t) + \frac{1}{T_i} \int_0^t e(\tau) d\tau + T_d \frac{d\, e(\tau)}{dt} \right]$$

Here, $\mathrm{e(t)}$ represents the error signal between the set-point (r) and the output signal, namely $\mathrm{e(t)} = \mathrm{r(t)} - \mathrm{y(t)}$, and $\mathrm{r(t)}$ is the reference input signal and is commonly called set point. The $\mathrm{u(t)}$ is the control signal that is proportional to $\mathrm{e(t)}$, proportional part, the integral part (integral of the error) and derivative of the error [3]. Thus, the control signal is the sum of the three terms. The controller parameters are proportional gain $\mathrm{K_p}$, integral time constant $\mathrm{T_i}$

and derivative time constant T_d. These are parameters to be tuned (Basilio & Matos, 2002).

Figure 1 presents the designed circuit diagram of an analog PI controller with operational amplifiers, proportional, integrator and summer. The components used to realize the electronic circuit of the PI controller is also shown in the figure. As shown, the power supply voltage used for OPA is $\mp$15V. The input variable signal was supplied using a function generator with a sinusoidal waveform of 1 volt in root-mean square amplitude. The set point was controlled by using a potentiometer as shown in figure.

For our purposes, a zero value has been chosen for the set-point. The controls of the gain parameters were controlled also using the corresponding potentiometers.

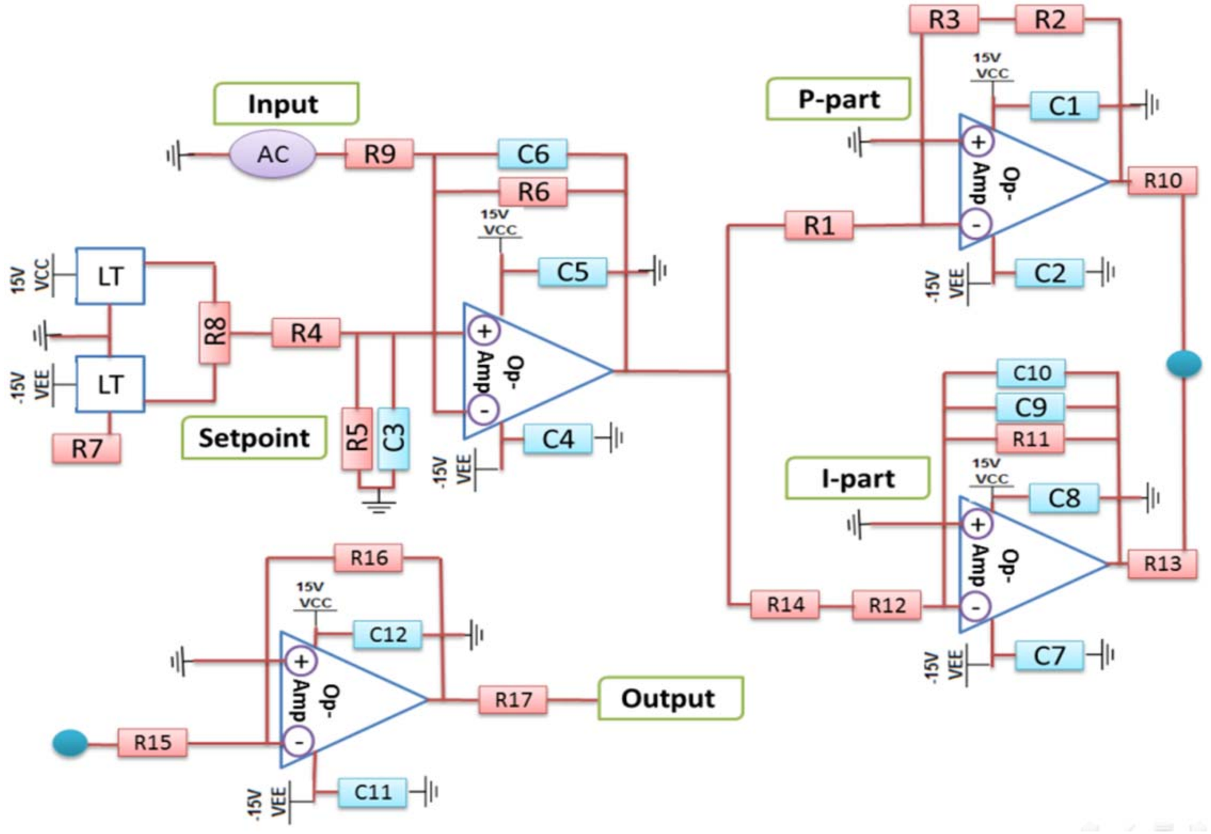

Figure (1): Sketch diagram of the designed PI controller.

In order to get the dynamics of the PI controller, we first study frequency response of the P part and the I part separately. Then we study the combination of parts. To do this, the following procedures have been followed: first we study the dynamic of P-part in term of frequency response. For this, we deactivate the I-term while adjusting the gain factor of P-part K_p into 0%, 50% and 100% of its maximum value. This has been done by adjusting the corresponding potentiometer. The same procedure has been done for I-part. As a result, we obtain two main features. First; we obtain the minimum and the maximum of the gain factor of each controller parts. Second, we obtain the frequency response of each part. The frequency response of a controller system generally is called bode plot. Briefly, bode plot consists of two graphs; one is a plot of the logarithm of the magnitude of a sinusoidal transfer function and the other is a plot of the phase angle. Both are plotted against the frequency scale. Simulated and experimental results of bode plot of term in P part is shown in figure 2 (a) and (b), respectively. The figure shows how the P part responds to the gain factor Kp.

As one can see, the gain response of P part is simply constant until 10 kHz. Then it begins to decrease by order of one which is still very fast for the system to respond the input variable. Furthermore, one can also see that with the predefined gain, we are able to increase or decrease the gain response by order of 2. From the figure, it’s clearly seen that the simulated gain response with respect to the measured one has almost the same behavior.

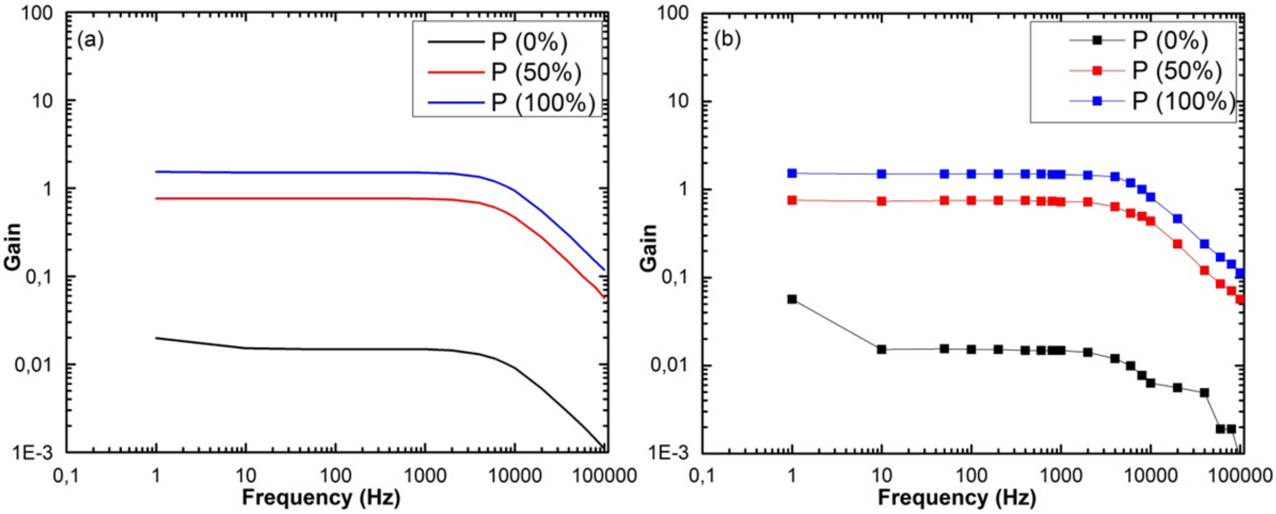

Figure (2): (a) Simulated and (b) experimental Bode plot of terms in P-part. The gain has been calculated as a function of frequency for three different Kp gain factor.

Ideally, in any control system the proportional gain could be made infinitely large so that the system becomes infinitely fast. However, this may lead to overshoot of the response system which pushes the controller system to be unstable. Figure 2 and 3 show good agreement between the experimental results with the corresponding simulated one. This gives the evidence that our designed controller system provides fast dynamics of the manufactured PI controller system.

Table (1): P and I parameters

Controller	K_P	T_i
P part (figure 2)	0%(black), 50% (Red), 100 % (blue)	0
I part (figure 3)	0	0%(black), 50%(Red), 100 % (blue)

On the other hand, the I part has completely different action on the control system. This difference is seen clearly in figure 3. From the figure the gain of the I part decreases very fast with respect to the frequency. It decreases by order of 2 when the input variable reaches 100 Hz. This is due to the integral term in I part. This means that this part is simply responses to low frequency in contradiction of the P part that response to high frequency. Like P part, a good agreement between the simulation results figure (a) and the corresponding experimental part figure (b) can be found respectively. The gain value of each parameter is presented in table 1.

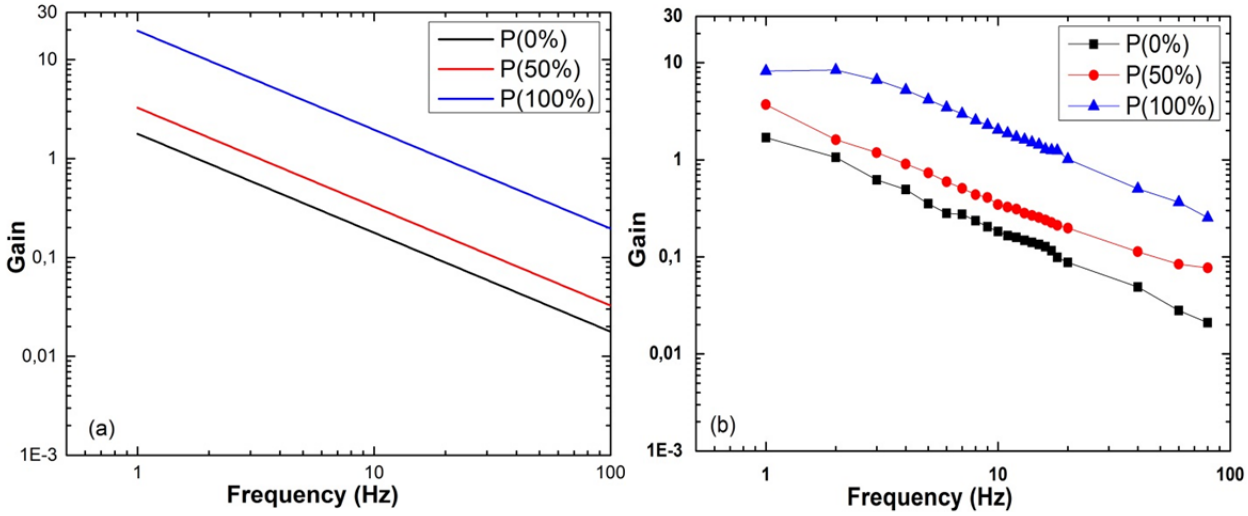

Figure (3): (a) Simulated and (b) experimental Bode plot of terms in I-part. The gain has been calculated as a function of frequency for three different T_i gain factors.

Now, by combining P and I terms, we observe different gain response of the system and this is shown in figure 4. In order to study the effect of each term, namely P and I part, we adjust the gain factor for each term. The following procedures are used for adjustment; First, we keep the $K_I = 0\%$ fix while adjust $K_p = 0\%$ and $K_p = 100\%$. Second, we set $K_p = 0\%$ fix while adjust $K_I = 0\%$ and $K_I = 100\%$. Now, by recording the output signal response we obtain gain response that is shown in figure 4. For the first case (setting $K_I = 0\%$) and adjusting the gain factor from $K_p = 0\% - 100\%$ the gain response is increased by order of one at low frequency while is increased by order of 2 at high frequency. This means that the P part lead the controller system to response very fast (which is obvious) with respect to the input variable. In opposite of the P part, the I part operate at low frequency. This is shown for case 2 ($K_p = 0\%$). We see clearly that the gain response is decreased by order of 2 until 100 Hz. This means that the I part forces the gain response to be closely infinite at very low frequency, namely at error steady state. The good agreement between the simulation part and the experimental measurement can be seen clearly in figure 4 (a) and (b), respectively. The gain value of each parameter is presented in table 2.

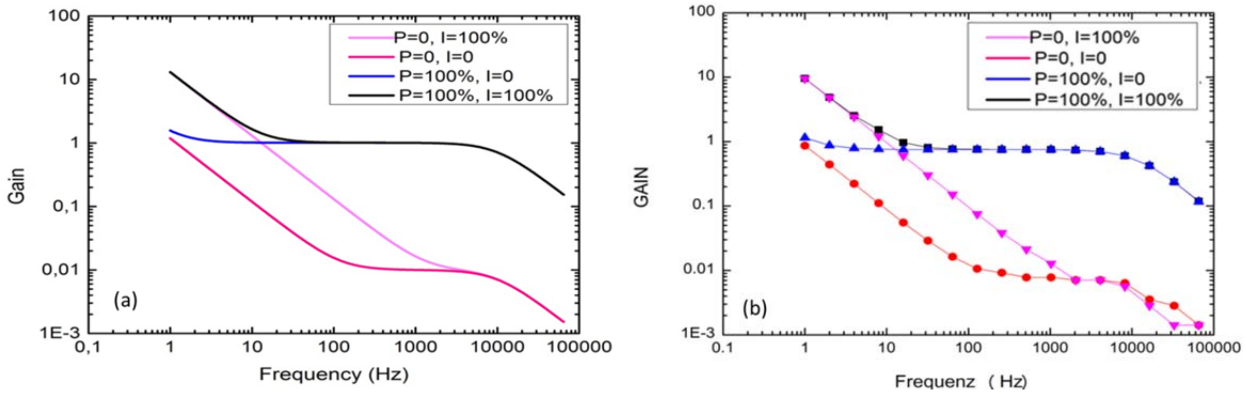

Figure (4): (a) Simulated and (b) experimental Bode plot of terms in PI-part. The gain has been calculated as a function of frequency for three different Kp and T_i gain factors.

Table (2): PI parameters

	Case (Colors)	K_p	T_i
PI part (figure 4)	Black	100 %	100 %
	Blue	100%	0%
	Red	0%	0%
	Pink	0%	100%

Conclusion

We show that our designed PI controller operate at low and high frequency. By studying the bode plot of each term, we show that P part is responsible for acting on the controller system at high frequency while the I part is responsible on low frequency. By comparing the experimental results with the simulated one, we show good agreement between them. Such controller system is of interest especially when workings with a system that need to have very fast response to any disturbance. A part of this work has been done at the University of Carl von Ozzientzky Universität Oldenburg/Germany.

Acknowledgement

The author would like to thank Professor Dr. Christoph Lienau and Mr. Raimond Angermann for the scientific support and devices.

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کورتیا لێکولینێ:

یاگونجایە کێمترین ژمارا پارامیترا هەبن ئەوێت تێنە زرنگاندن بو زالکرنا سیستەمەکی. زالگەکەرێ داتاشراوی-تەواوکاری یێ ریژاوی (PID) ئەڤ ساخلەتە یێ هەی ونوکە روژانە تێنە بکارئینان ل بوارێت کارەکی یێت جودا جودا بتایبەتی د سیستەمێ زالکرنا پیشەیی دا. بو بدەستڤەئینانا بەرسڤا لەرەلەری یا وەك ڤی زالگەکەری بو هەر نبشانەکا شێواندنێ، تەکنیکەکا دارشتنا گونجای پێدڤێت. ل ڤێرێ مە زالگەکەرەکێ PI یێ تاقیگەهی چێکر و هاتە نواندن بکارئینانا بەرنامێ مەلتیسم Multisim software. مە برسڤدانا لەرەلەری یا دارشتەییێ زالگەهکەرێ PI خاند. مە دیت کو زالگەکەرێ PI ئەوێ هاتیە چێکرن بەرسڤدانەکا بلەز یا هەی (دسەر KHz 10) بو هەر شێواندنەکێ. مە دیت سازانەکا مەزن یا هەی ناڤبەرا نواندنێ و پشکا تاقیکرنێ. وێنێ بود bode plot ئەوێ بەرسڤا لەرەلەرا سیستەمی ددەتە مە یێ هاتیە هژمارکرن و پیڤان. ئەڤ خاندنا یا گرنگە ژبو ژمارەکا کارپێکەریا ب تایبتی د بوارێ هویربینیا هێزا گەردیلەیی (AFM)، سکانکرنا هویربینیا نەقەبکرنێ (STM) و سیستەمێت دی یێت زالکرنا پیشەیی ئەوێت پێتڤی ب بەرسڤدانا بلەز یا زالکرنا سیستەمی.

الملخص:

من الملائم أن يكون لدينا الحد الادنى من المعلمات المطلوب تنغيمه لاي نظام تحكم. معاملات المنفصلة التناسب(P)، التكامل(I)، والتفاضل (D) يتكون من هذه الخاصية ويستعمل يومياً في الكثير من الأنضمة التحكمية خاصةً انضمة تحكم السيطرة الصناعية. لكي نحصل على استجابة التردد لمثل هكذا نظام ،نحتاج لتصميم تقنية مناسبة. نحن صنعنا عملياً وحاكيناه بواسطة لغة الكمبيوتر Multisim نظام التناسب(P) و التكامل (I) . وقد درسنا على استجابة التردد ال- PI وبينا أن النظام المصنوع لديه إستجابة سريعة جداً يصل فوق ١٠٠ كيلو هيرتز. وبينا أنه هناك تناغم بين العملي والمحكات النظرية. هذا مهم لكثير من التطبيقات مثل مجهر القوة الذرية AFM و–مجهر المسح النفقي STM.