ECE 445 Project Proposal
#4 Instant Nitro Cold Brew Machine

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1. Introduction:

a. Problem:

Cold brew is made by steeping coffee grounds in cold water for 12-18 hours. This low-temperature steeping extracts fewer bitter compounds than traditional hot brewing, leading to a more balanced and sweeter flavor. While cold brew can be prepared in big batches ahead of time and stored for consumption throughout the week, this would make it impossible for someone to choose the specific coffee beans they desire for that very morning. The proposed machine will be able to brew coffee in cold water in minutes by leveraging air pressure. The machine will also bring the fine-tuning and control of brewing parameters currently seen in hot brewing to cold brewing.

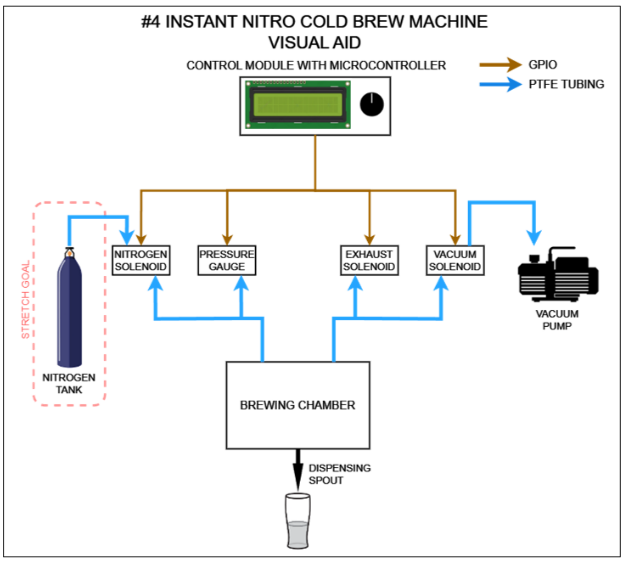
b. Solution:

The brew will take place in an airtight aluminum chamber with a removable lid. The user can drop a tea-bag like pouch of coffee grounds into the chamber along with cold water. By pulling a vacuum in this chamber, the boiling point of water will reach room temperature and allow the coffee extraction to happen at the same rate as hot brewing, but at room temperature. Next, instead of bringing the chamber pressure back to atmospheric with ambient air, nitrogen can be introduced from an attached tank, allowing the gas to dissolve in the coffee rapidly. The introduction of nitrogen will prevent the coffee from oxidizing, and allow it to remain fresh indefinitely. When the user is ready to dispense, the nitrogen pressure will be raised to 30 PSI and the instant nitro cold brew can now be poured from a spout at the bottom of the chamber.

The coffee bag prevents the coffee grounds from making it into the drink and allows the user to remove and replace it with a bag full of different grounds for the next round of brewing, just like a Keurig for hot coffee.

To keep this project feasible and achievable in one semester, the nitrogenation process is a reach goal that we will only implement if time allows. Since the vacuum and nitrogenation phases are independent, they can both take place through the same port in the brewing chamber. The only hardware change would be an extra solenoid control MOSFET on the PCB.

c. Visual Aid:

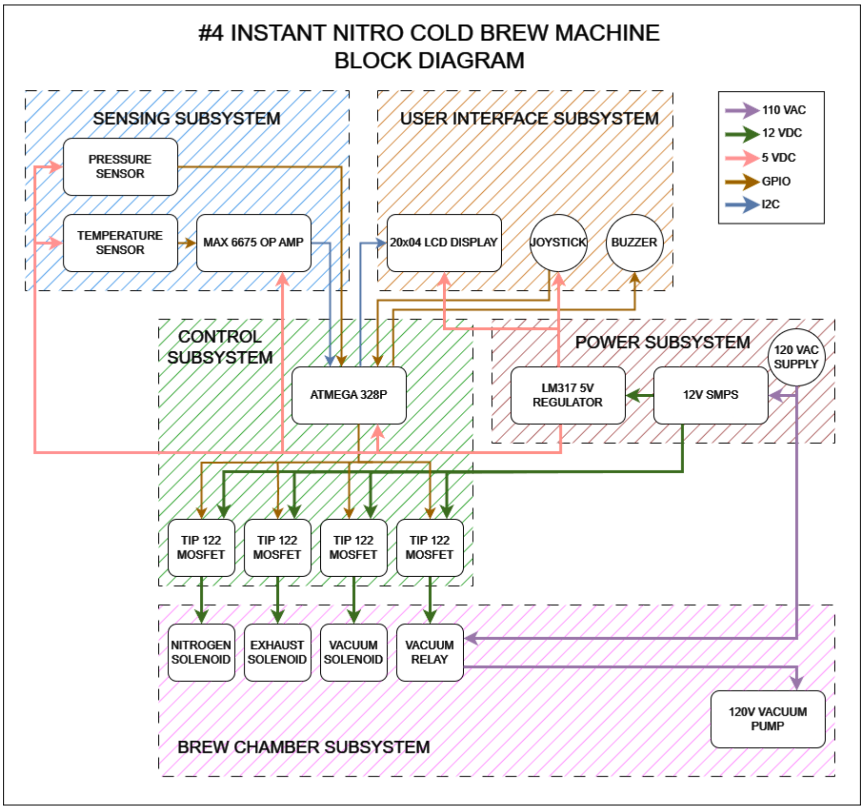


d. High-Level Requirements: provide some specific numbers

1. A successful cold brew machine would be able to make cold brew coffee using water at a maximum of 25°C in under 10 minutes.
    1.1. The error tolerance for the temperature of the brew is ±5°C.
    1.2. The error tolerance for the brew time is ±3 minutes.
    1.3. Our requirement for "cold brew coffee" is that it must not have the acidic taste found in a hot-brewed iced coffee made from the same beans.
2. The machine must allow the user to manually control the brew time, brew pressure, and also display the brew temperature.
    2.1. The user must be able to set the brew time between 0 and 15 minutes. The machine's duration of the brew phase must be within ±5 seconds of the user's desired brew time.
    2.2. The user must be able to set the brew pressure between 1 and 7 PSI. The brew pressure maintained by the machine when in the brew phase must be within ±0.5 PSI of the user's desired brew pressure.
3. The machine must detect faults and reach a safe stop-state. It must convey this error through a human readable error code and sound a buzzer if human intervention is needed. The primary failure modes are:
    3.1. Loss of Solenoid Control: given the importance of the solenoids in this project, unresponsive solenoids must trigger the buzzer and call for human intervention to shut down the machine
    3.2. Loss of Pressure: Once the chamber is prepared, a nominal leak rate will be established. A pressure loss rate 20% above the nominal leak rate must abort the brew cycle and display the appropriate error code.

2. Design:

a. Block Diagram:



b. Subsystem Overview:

1. UI Subsystem: This subsystem allows the user to interact with the brew settings of the machine. Using a 2-axis joystick with a built-in push-button, the user can navigate a menu to set their desired brew pressure, brew time and view the brew temperature and time remaining.

   The UI also displays the human readable error codes when the machine detects a fault. The buzzer is used to notify the user when the brew is complete, or when there is an error that needs user intervention.

   The UI subsystem is connected to the Control subsystem through I2C for the LCD Display and GPIO for the buzzer and joystick.

2. Control Subsystem: This subsystem contains the microcontroller for this machine. It stores the brew parameters input by the user through the UI, and runs through the different states of the machine. Using the TIP122 MOSFETs, the control subsystem can control the vacuum solenoid, exhaust solenoid, nitrogen solenoid, and the vacuum pump relay. It uses measurements from the sensing subsystem to compute the brew temperature, and maintain the correct chamber pressure using the vacuum pump.

3. Sensing Subsystem: The sensing subsystem is responsible for measuring the pressure and temperature in the brewing chamber. The pressure sensor selected has a linear analog output and can be connected directly to the Control subsystem. The selected temperature sensor is a K-type thermocouple and will communicate to the Control subsystem using I2C through the MAX6675 OpAmp.

4. Brewing Subsystem: The brewing subsystem consists of the valves and vacuum pump. When the vacuum pump is powered off, air can leak into the chamber through its exhaust port. The vacuum solenoid valve is used to cut off the connection to the vacuum pump when it is not on to prevent such a leak. The relay used to control the vacuum pump is a 5V relay capable of switching up to 5A at 250V. The nitrogen tank is connected and disconnected from the brew chamber using the nitrogen solenoid valve. Finally, the exhaust solenoid is a safety mechanism used to release any pressure in the chamber in the case that an error is detected. By opening this solenoid, any vacuum or positive nitrogen pressure can be released. The exhaust solenoid will also need to be opened when dispensing the coffee.

5. Power Subsystem: The power subsystem is responsible for providing the 12VDC for the solenoids and the 5VDC for the Control and Sensing subsystems. A 70W 12V SMPS is used to bring 110AC down to 12VDC to power the solenoids. An LM317 configured as a 5V regulator is used to bring the 12VDC down to 5VDC to power the Control and Sensing subsystems.

c. Subsystem Requirements:

1. UI Subsystem: The UI subsystem consists of one LCD display, one 2-axis joystick with a push button, and a buzzer. The LCD display communicates with the microcontroller over I2C. The joystick and buzzer are connected to GPIO pins. Requirements for the UI Subsystem:

1.1. The default/idle screen of the LCD Display must display the current temperature and pressure, the time remaining, a start/stop button, and an option to enter the settings sub-menu.
1.2. The settings sub-menu must allow the user to set desired brew time and pressure, and the machine must accomplish this brew time and pressure following the tolerances in Section 1.d.2.1 and 1.d.2.2.
1.3. Each sub-menu page must have an option to return to the previous menu page. Selecting brew time or pressure must allow adjustment using the X-axis of the joystick, and pressing the joystick must enter the currently displayed selection.
1.4. On the detection of an error, the display must revert to the idle screen, displaying a human readable error code and a selection to restart the machine.
1.5. Starting a brew cycle must disable the option to enter the settings sub-menu, and the start button must become a stop button.
1.6. A buzzer must sound when the brew is complete. This sound must be short, and distinct, not easily confused with the sound made for an error state needing user attention.

2. <u>Control Subsystem:</u> The control subsystem is responsible for controlling all other subsystems in the machine. Beyond communication with the UI subsystem, the control subsystem communicates with the pressure and temperature sensor using GPIO and I2C respectively. The control subsystem operates on 5VDC and is powered by the power subsystem. It controls the solenoids and vacuum relay through four TIP122 MOSFETs.
    2.1. The control subsystem must reset the brew time and brew pressure to 10 minutes and 1 PSI respectively on each power cycle of the machine.
    2.2. The control subsystem must measure the analog signal from the pressure transducer and evaluate the chamber pressure accurately to 0.1 PSI precision to display on the UI subsystem LCD. It must also communicate with the thermocouple OpAmp over I2C and evaluate the brew temperature accurately to 0.1°C precision to display on the UI subsystem.
    2.3. The control subsystem must control the three pneumatic solenoids and vacuum pump relay using four GPIO pins through the TIP122 MOSFETs.

3. <u>Sensing Subsystem:</u> The sensing subsystem consists of the pressure transducer and temperature thermocouple. The pressure transducer's output is an analog signal which will directly connect to an analog input on the control subsystem's microcontroller. The temperature thermocouple requires an OpAmp for its values to be read accurately by the microcontroller. The OpAmp must have a distinct I2C address and send the recorded thermocouple voltage to the microcontroller.

4. <u>Brewing Subsystem:</u> The brewing subsystem consists of the three pneumatic solenoid valves and the vacuum pump relay - it is primarily made up of mechanical components. The brewing subsystem must have all electronics operating at 12V or higher physically separated from it. The pressure gauge and three pneumatic solenoids must be mounted above the chamber, and have electrical overrides to actuate the solenoids without microcontroller intervention. The brew chamber's lid must be easily removable for cleaning, and there must be a dispensing spout at the bottom. The chamber must have a peg inside to tie the coffee bag to.

5. Power Subsystem: The power subsystem consists of the 12VDC SMPS and 5V regulator. The 12V SMPS must provide 12V at 7A continuous, with a maximum voltage error of ±0.5V. The 5V regulator must provide 5V from the 12V supply with a maximum error of ±0.3V at 500mA continuous. At peak current draw, when the 5V relay is actuated, the voltage must not drop beyond the ±0.3V tolerance mentioned above.

d. Tolerance Analysis:

The brewing chamber is essentially a vacuum chamber, and designing it such that there is no risk of implosion is critical to the success of this project. The vacuum chamber will be a cylindrical chamber, capped at two ends, made from aluminum. The thickness of the chamber walls has been selected to have a very high safety margin. The calculations below (C. Hauviller, 2007) find the equivalent stress in the chamber assuming a perfect vacuum:

radius = 160mm/2 = 0.08m

thickness = 6 mm = 0.006 m

Atmospheric Pressure = 1 bar = 10^5 Pa

circumferential stress = $\sigma_\theta = \frac{pR}{t}$ — p = external pressure, R = radius, t = thickness

$$\Rightarrow \sigma_\theta = \frac{10^5 \text{ Pa} \cdot (0.08)}{0.006} = 1.\overline{33} \text{ MPa}$$

The chamber is closed with 6mm aluminum (caps), thus axial force is: $F = p \times A = 10^5 \text{ Pa} \times \pi r^2$

$$= 10^5 \text{ Pa} \times \pi \times 0.08^2$$

$$= 2010.619$$

now, axial stress is:

$$\sigma_z = \frac{pR}{2t} + \frac{F}{2\pi R t} = \frac{2010.619}{2\pi(0.08)(0.006)} = 66.67 \times 10^4$$

$$\frac{pR}{2t} = \sigma_\theta / 2$$

Von Mises equivalent stress:

$$\sigma_e = \frac{1}{2}\left[3\left(\frac{pR}{t}\right)^2 + \left(\frac{F}{\pi R t}\right)^2\right]^{1/2}$$

substituting values, $\sigma_e = 1.\overline{33}$ MPa

The maximum allowable stress for aluminum alloys varies from 144 MPa to 300 MPa. For our calculations, we will assume the low end stress of 144MPa. Given that the maximum equivalent stress on our vacuum chamber is 1.33 MPa, the maximum stress is over 100 times less than the maximum allowable stress for aluminum. This large safety factor, along with a thorough testing of the chamber, allows for the safe use of this machine.

3. Ethics and Safety:

The main ethical matter when it comes to this project is with regard to the safety of the machine. This falls under the first section of the IEEE code of ethics in which we are required to hold paramount the safety of the public. One safety hazard is the possibility of a burnt BJT. If the BJT overheats, there is a possibility of the solenoid getting stuck in the on or off position. We will solve this using a safety precaution built into the microcontroller that will use a voltage divider to monitor the voltage across the solenoid. This will allow us to end the procedure by use of the exhaust solenoid. Using this exhaust solenoid, there will also be safety measures in place to protect from abnormal amounts of pressure in the chamber. These measures will all be indicated by error codes that appear on the LCD display.

Another concern with our project is related to the use of nitrogen gas. We are using nitrogen with the purpose of infusing the coffee with nitrogen to achieve a flavor many coffee lovers desire. We must handle the nitrogen tank with care and make sure to never release large amounts of nitrogen in an indoor environment. While nitrogen gas makes up most of the air we inhale, releasing large amounts in enclosed environments can be dangerous. For this reason the nitrogen tank is equipped with a main shut off valve that we will use to control the amount of nitrogen we will be releasing. For this project, the amount of nitrogen that would ever be exhausted into the atmosphere would create a negligible impact on the air around the machine.

Other than these safety concerns, there are many ethical matters that we must take into account when working on this project. The IEEE code of ethics provides the standard for us as engineers. Some important points to emphasize from the code that pertain to our project are seeking criticism and treating everyone fairly and with respect. An important aspect of the project is seeking criticism and looking for help. We will be constantly searching for people to help with specific aspects of the project such as the writing and mechanical components. It is also important that we are in constant contact with our TA to hear and discuss criticisms of the project. Looking for help also ties into treating everybody involved with respect. This project involves many people who all must be treated with respect at all times. We must not only uphold the standards set by the IEEE, but also go beyond and practice good ethics in all scenarios, even those not outlined by the code of ethics.

4. Citations:

1. C. Hauviller, 2007. Design Rules for Vacuum Chambers. https://cds.cern.ch/record/1046848/files/p31.pdf