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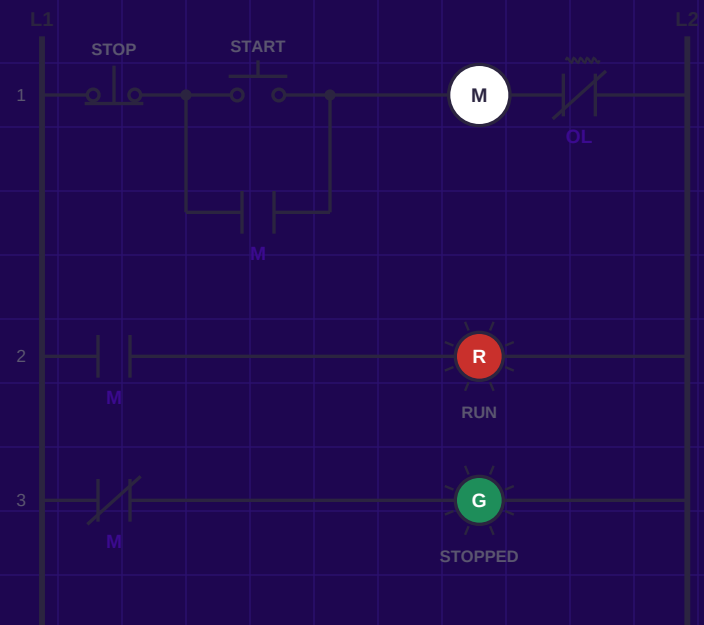
FREE STUDY GUIDE

# 27

## Motor Control Circuits

Step by step, with ladder diagrams (NEMA style)

- Start/stop, jog and pilot lights
- Forward/reverse and limit switches
- Wye-delta, two-speed and sequences
- Timers, floats, pressure and lighting
- Emergency stop with master relay



# Before you start

This guide shows 27 control circuits used every day in motors, pumps, compressors, fans and lighting. Each page has a ladder diagram, the list of components, how it works step by step and a tip from the field.

Diagrams use NEMA symbols, the standard in the United States and Canada. The left rail (L1) and the right rail (L2 or neutral) are the control power; each horizontal line is a rung.

Study one circuit at a time: read the steps while you follow the current with your finger on the diagram. Then try to explain it out loud without looking.

## ! SAFETY FIRST

- Turn off and lock out the power (LOTO) before touching any wiring.
- Test for absence of voltage with a meter you trust, every time.
- Use tools and PPE rated for the voltage you work with.
- Only qualified electricians should install or modify industrial equipment.
- This guide is study material. It does not replace the NEC, local codes, the manufacturer's instructions or a licensed professional.

# How to read a ladder diagram

- Current 'flows' from the left rail to the right rail through each rung.
- Contacts (inputs) are on the left; the load (coil, light) is on the right.
- Contacts are drawn in their NORMAL state: not pressed, not energized.
- A contact with the same tag as a coil (e.g. M) changes when that coil is energized.
- Overload (OL) contacts are usually drawn to the right of the coil.

## SYMBOL LEGEND

 Contact NO (normally open)

 Contact NC (normally closed)

 Pushbutton NO (start)

 Pushbutton NC (stop)

 Emergency stop (mushroom)

 Selector switch contact

 Maintained switch

 Coil (contactor / relay)

 Timer coil

 Timed contact NO (on-delay)

 Timed contact NC (on-delay)

 Timed contact NO (off-delay)

 Overload contact NC

 Limit switch NC

 Limit switch NO

 Float switch NO

 Pressure switch NC

 Thermostat NO

 Photocell

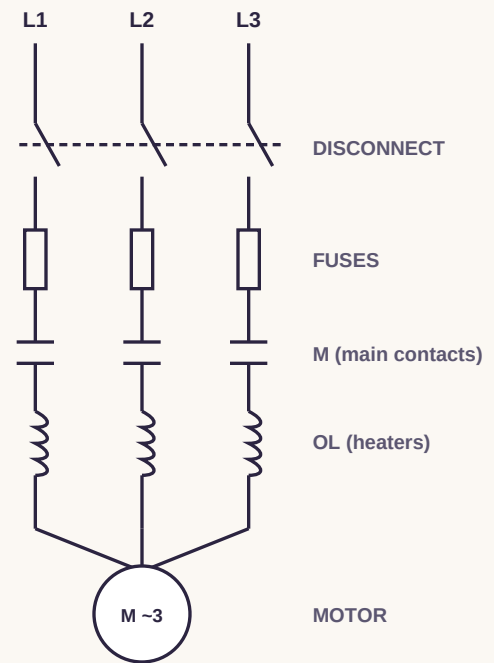
 Pilot light

# Power circuit vs. control circuit

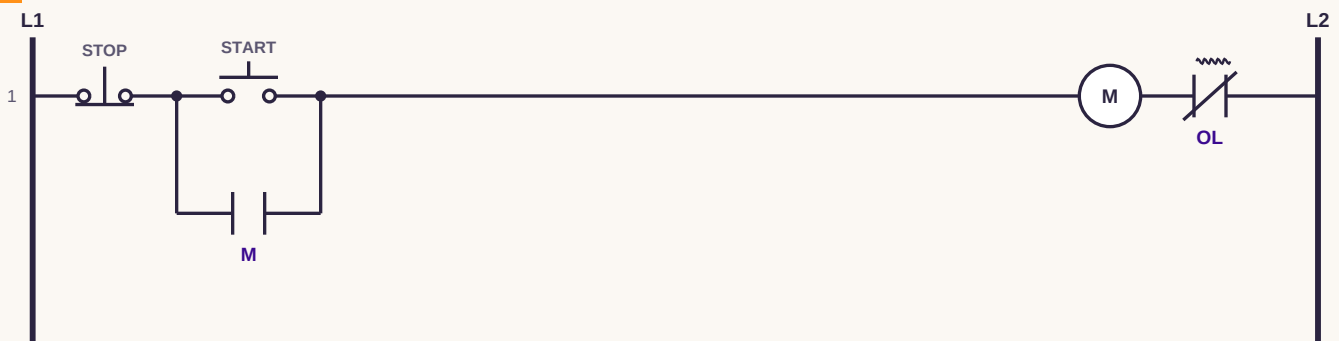
The POWER circuit carries the motor current: disconnect, fuses or breaker, the main contacts of the starter (M), the overload heaters (OL) and the motor.

The CONTROL circuit decides WHEN the starter closes: pushbuttons, switches, relays, timers and the coil of M. It usually runs at 120 V AC or 24 V from a control transformer.

Every circuit in this guide is a CONTROL circuit. The power circuit of a simple motor (direct-on-line) is the one on this page.



## CONTROL CIRCUIT (LADDER DIAGRAM)



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# Two-wire control (maintained switch)

## WHAT IT DOES

The simplest motor control: a maintained switch turns the starter on and off. If power fails and comes back, the motor restarts by itself.

### CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- SW: maintained toggle or selector switch
- M: motor starter coil (contactor)
- OL: overload relay contact (NC)

## HOW IT WORKS, STEP BY STEP

- 1 Close SW: current flows through SW, the M coil and the OL contact.
- 2 M pulls in and its main contacts start the motor.
- 3 Open SW: M drops out and the motor stops.
- 4 On overload, OL opens and stops the motor.

## PRO TIP

Two-wire control gives low-voltage RELEASE: the motor restarts on its own when power returns. Never use it where a surprise restart can hurt someone.

# Three-wire start/stop with seal-in

## WHAT IT DOES

The classic motor starter: momentary START and STOP pushbuttons with an M auxiliary contact that holds the coil on.

### CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- STOP: pushbutton NC
- START: pushbutton NO
- M: starter coil + auxiliary NO contact (seal-in)
- OL: overload contact NC

## HOW IT WORKS, STEP BY STEP

- 1 Press START: the M coil energizes.
- 2 The M auxiliary contact closes in parallel with START and seals the circuit.
- 3 Release START: M stays on through its own contact.
- 4 Press STOP (or OL trips): the circuit opens, M drops out and the seal-in opens.

## PRO TIP

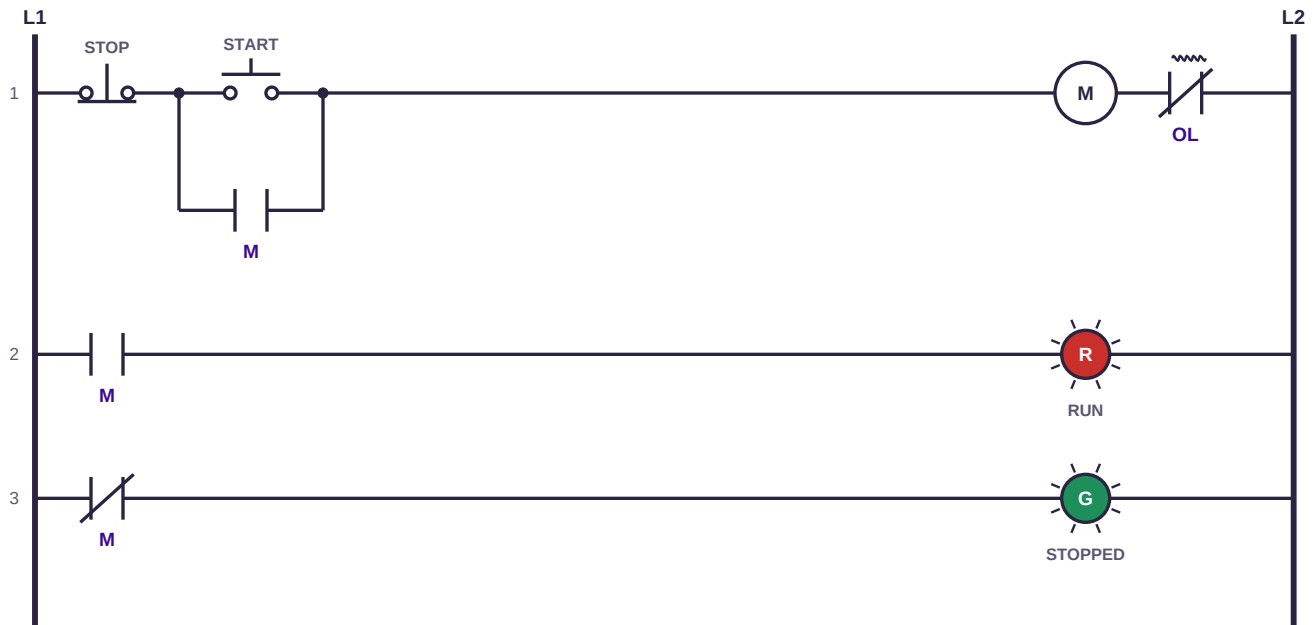
This is low-voltage PROTECTION: after a power failure the motor stays off until someone presses START again.

# Start/stop with RUN and STOPPED pilot lights

## WHAT IT DOES

Same three-wire circuit plus two pilot lights so the operator sees at a glance if the motor is running.

### CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- STOP / START pushbuttons
- M: coil with 2 NO and 1 NC auxiliary contacts
- Red pilot light: running
- Green pilot light: stopped
- OL: overload contact NC

## HOW IT WORKS, STEP BY STEP

- 1 At rest, the M NC contact is closed: the green light is ON.
- 2 Press START: M pulls in, seals itself and the motor runs.
- 3 The M NO contact turns the red light ON and the M NC contact turns the green light OFF.
- 4 Press STOP: everything returns to rest.

### PRO TIP

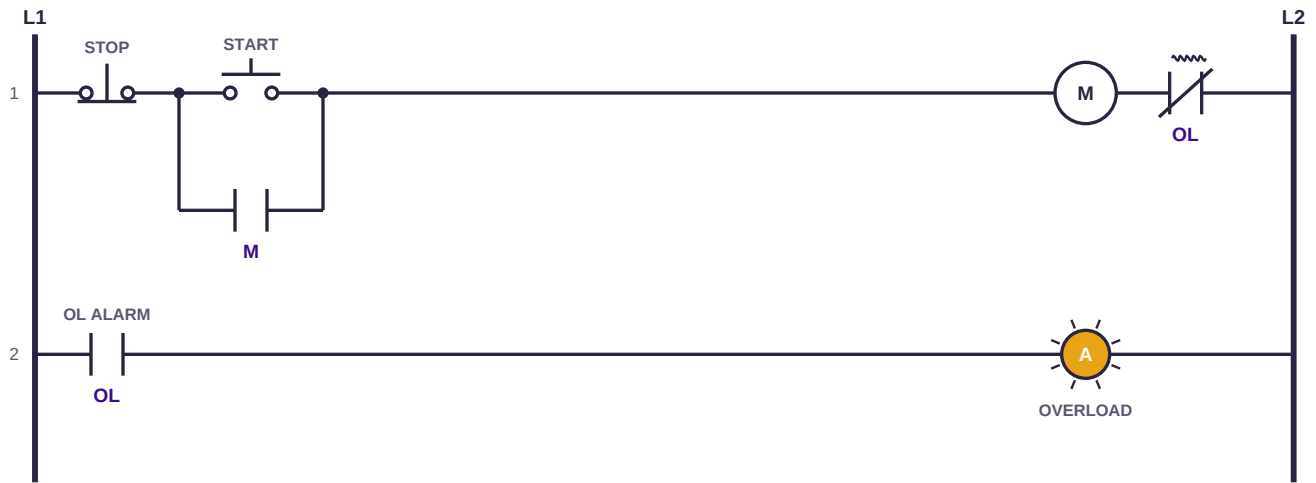
Colors vary by plant: many US industrial sites use red = running (energized) and green = stopped (safe). Follow the standard of the place where you work.

# Overload trip alarm light

## WHAT IT DOES

Uses the NO alarm contact of the overload relay to turn on an amber light when the motor trips on overload.

CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- Overload relay with NC trip contact (95-96) and NO alarm contact (97-98)
- Amber pilot light
- STOP / START / M as in circuit 02

## HOW IT WORKS, STEP BY STEP

- 1 Normal run: the 95-96 contact is closed and the 97-98 contact is open.
- 2 On overload, the relay trips: 95-96 opens and M stops.
- 3 At the same time, 97-98 closes and the amber light turns ON.
- 4 After fixing the cause, press RESET on the relay: the light goes OFF.

## PRO TIP

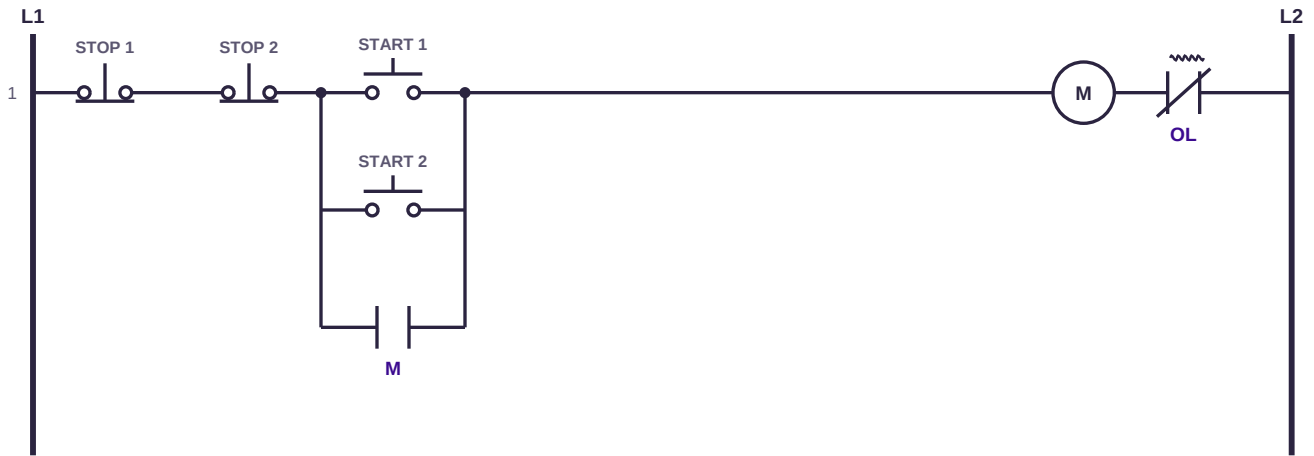
A trip is a symptom. Before resetting, check the load, the voltage on the three phases and the setting of the relay (motor nameplate FLA).

# Start/stop from two locations

## WHAT IT DOES

Lets the operator start and stop the same motor from two stations, for example at the machine and in the control room.

### CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- 2 STOP pushbuttons NC (in SERIES)
- 2 START pushbuttons NO (in PARALLEL)
- M: coil + seal-in contact
- OL: overload contact

## HOW IT WORKS, STEP BY STEP

- 1 Any START button energizes M.
- 2 The M contact seals the circuit.
- 3 Any STOP button opens the series path and stops the motor.
- 4 Add as many stations as needed: stops in series, starts in parallel.

## PRO TIP

Easy rule to remember: STOPS in series, STARTS in parallel.

# Jog with RUN/JOG selector switch

## WHAT IT DOES

A selector switch breaks the seal-in so the START button can 'jog' the motor in small steps for setup and alignment.

### CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- STOP / START pushbuttons
- SS: 2-position selector RUN / JOG
- M: coil + seal-in contact
- OL: overload contact

## HOW IT WORKS, STEP BY STEP

- 1 Selector in RUN: the seal-in path is complete and the circuit works like circuit 02.
- 2 Selector in JOG: the seal-in path is open.
- 3 In JOG, the motor runs only while START is held down.
- 4 Release START: the motor stops right away.

## PRO TIP

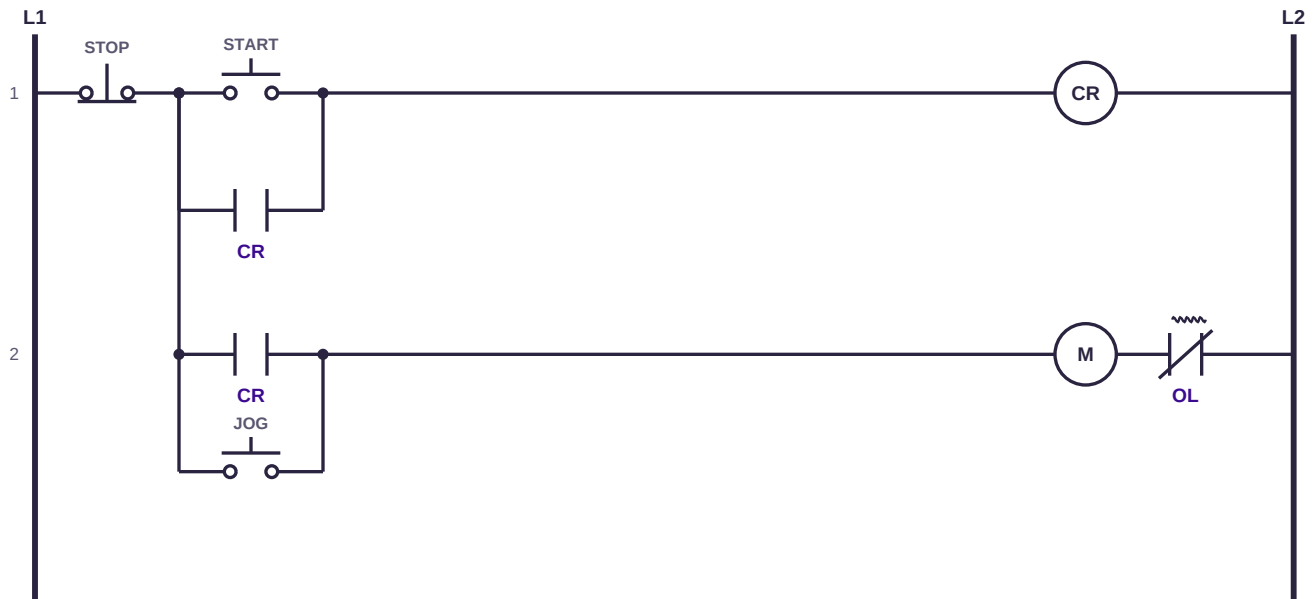
Jogging makes many starts in a short time. Check that the motor and starter are rated for jogging duty.

# Jog with a jog pushbutton and control relay

## WHAT IT DOES

A separate JOG button and a control relay (CR) let the operator run or jog without a selector switch.

CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- STOP / START / JOG pushbuttons
- CR: control relay (2 NO)
- M: starter coil
- OL: overload contact

## HOW IT WORKS, STEP BY STEP

- 1 START energizes CR, which seals itself.
- 2 A CR contact energizes M: the motor runs continuously.
- 3 JOG energizes M directly, without sealing: the motor runs only while JOG is pressed.
- 4 STOP drops CR and the motor stops.

## PRO TIP

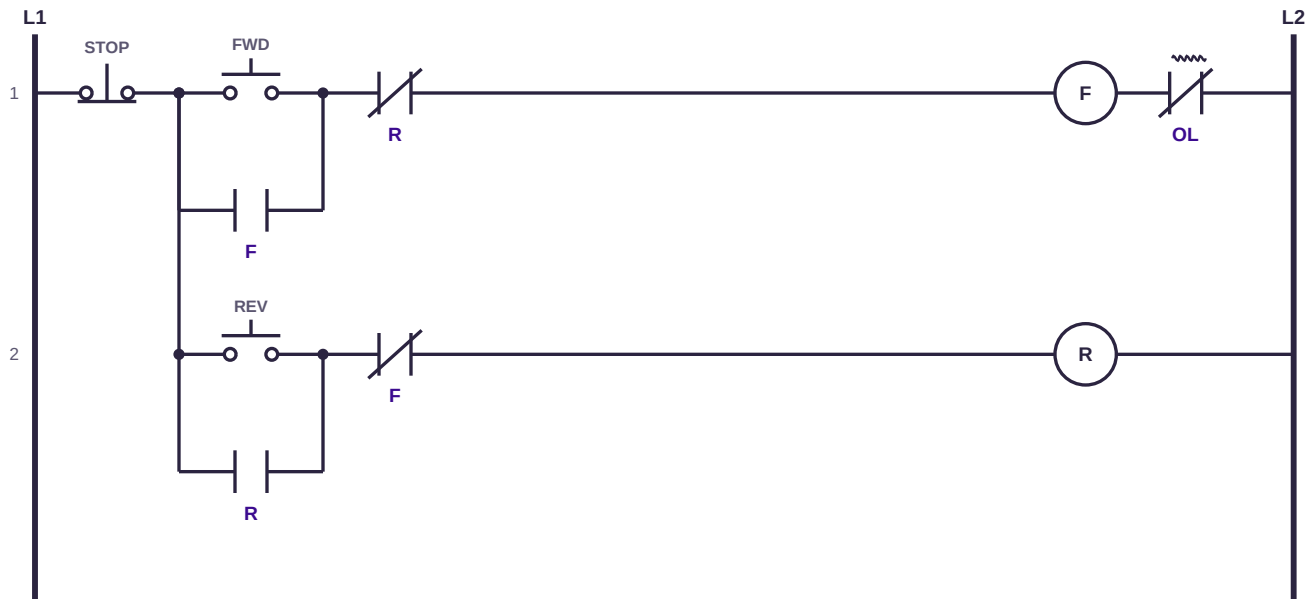
Notice that M has no seal-in contact of its own: the seal is on CR. That is what makes the JOG button safe.

# Forward/reverse with electrical interlock

## WHAT IT DOES

Two starters (F and R) swap two phases to reverse the motor. NC contacts of each starter block the other one.

### CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- STOP, FWD and REV pushbuttons
- F and R: reversing starter (2 contactors)
- NC auxiliary contacts of F and R (interlock)
- One overload relay for the motor

## HOW IT WORKS, STEP BY STEP

- 1 Press FWD: F energizes, seals itself and opens its NC contact in the R line.
- 2 With F on, pressing REV does nothing.
- 3 To change direction, press STOP first, wait for the motor to slow down, then press REV.
- 4 The same happens in reverse: R blocks F.

### PRO TIP

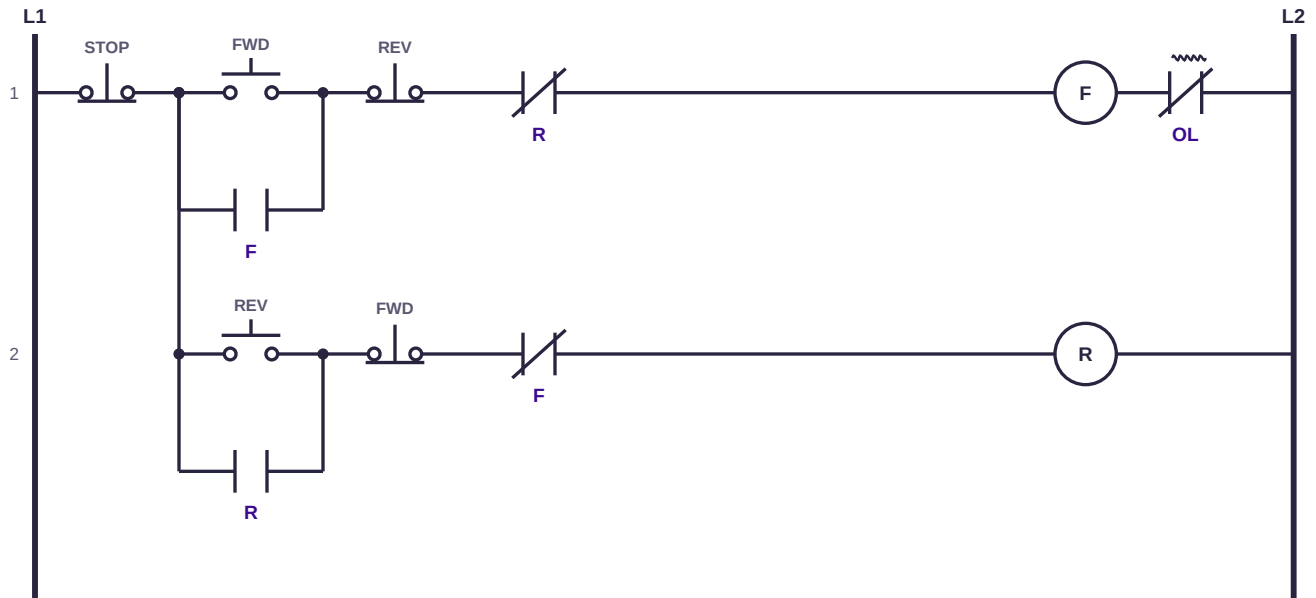
Without the interlock, F and R could close together and make a phase-to-phase short circuit. Most reversing starters also have a mechanical interlock.

# Forward/reverse with double interlock

## WHAT IT DOES

Adds pushbutton interlock: each direction button has an NC contact that opens the opposite coil, so you can change direction without pressing STOP.

### CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- FWD and REV pushbuttons with 1 NO + 1 NC each
- STOP pushbutton
- F and R contactors with NC auxiliaries
- Overload relay

## HOW IT WORKS, STEP BY STEP

- 1 Press FWD: its NC side opens the R line and its NO side energizes F.
- 2 While running forward, press REV: the REV NC side drops F.
- 3 When F drops, its NC contact closes and R can energize.
- 4 Two interlocks (buttons + contacts) protect against short circuits.

## PRO TIP

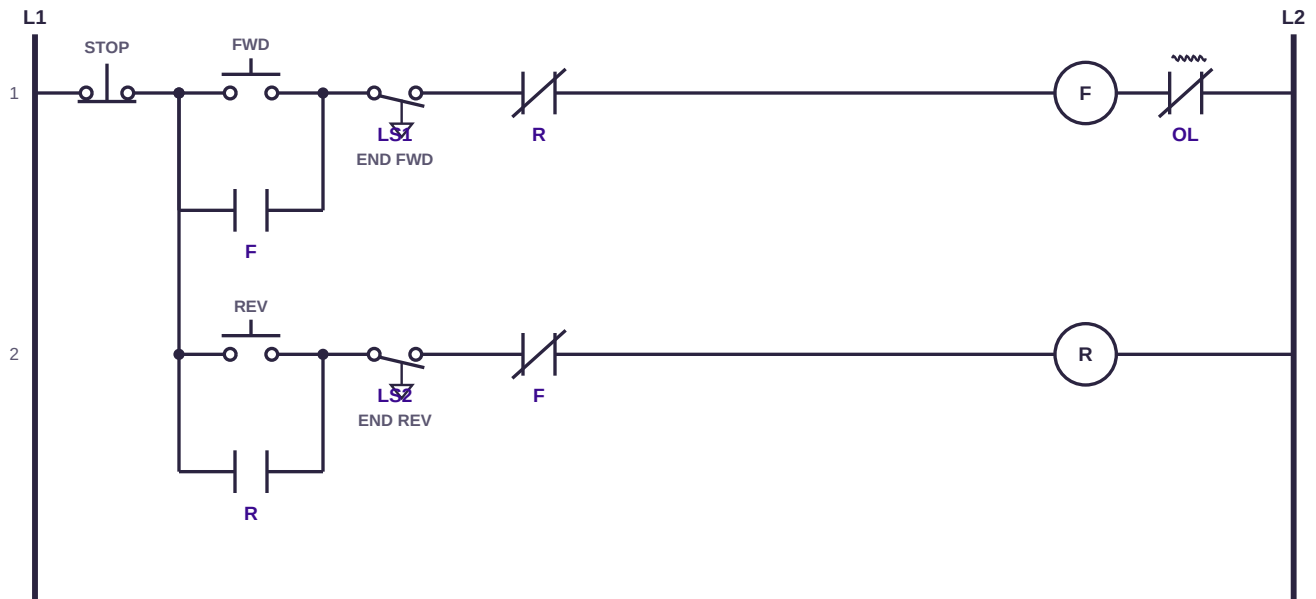
Reversing a motor at full speed (plugging) causes very high current and mechanical stress. Use it only where the load allows it.

# Forward/reverse with limit switches

## WHAT IT DOES

Limit switches stop each direction automatically at the end of travel, as in gates, carts and hoists.

CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- LS1 and LS2: limit switches NC
- STOP, FWD, REV pushbuttons
- F and R contactors with interlock
- Overload relay

## HOW IT WORKS, STEP BY STEP

- 1 Press FWD: the load moves forward.
- 2 At the end of travel the load hits LS1, which opens and drops F.
- 3 FWD will not work again while LS1 is pressed, but REV works.
- 4 Press REV: the load moves back until LS2 stops it.

## PRO TIP

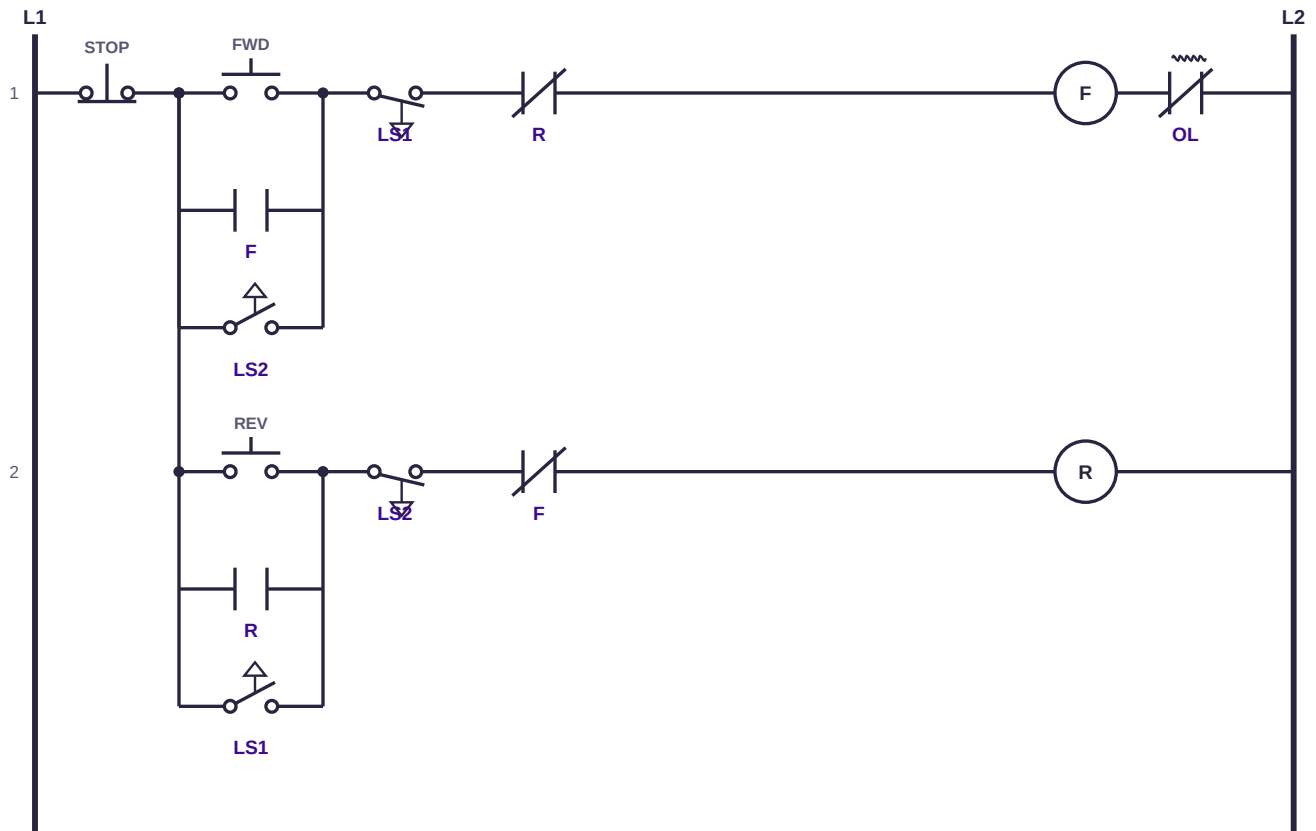
Put the limit switch a little before the mechanical stop, and on hoists add a second (final) limit as a backup.

# Automatic back-and-forth with limit switches

## WHAT IT DOES

The load travels forward and backward by itself: each limit switch stops one direction and starts the other.

### CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- LS1 and LS2: limit switches with 1 NO + 1 NC each
- STOP, FWD, REV pushbuttons
- F and R contactors with interlock
- Overload relay

## HOW IT WORKS, STEP BY STEP

- 1 Press FWD: the load moves forward.
- 2 At the end it hits LS1: the NC side drops F and the NO side starts R.
- 3 The load moves back until it hits LS2, which drops R and starts F again.
- 4 The cycle repeats until someone presses STOP.

## PRO TIP

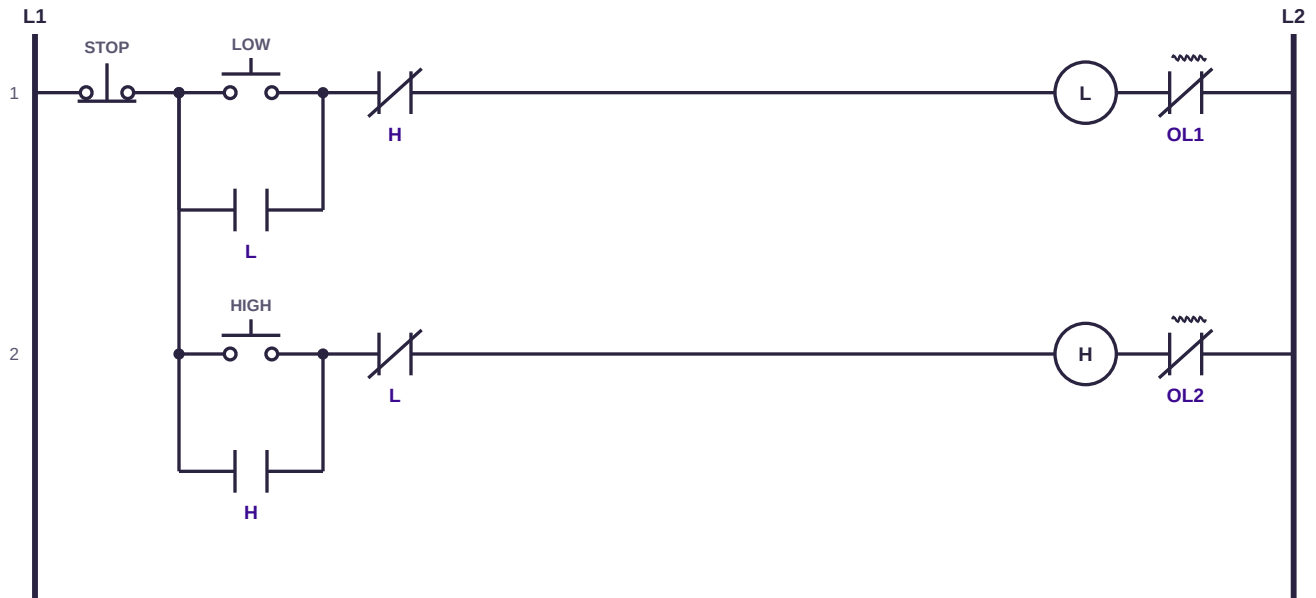
For heavy loads, add a short time delay before reversing so the motor stops before changing direction.

# Two-speed motor (separate windings)

## WHAT IT DOES

Two contactors, LOW (L) and HIGH (H), each feed one winding of the motor. They are interlocked so only one speed runs at a time.

### CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- STOP, LOW and HIGH pushbuttons
- L and H contactors with NC interlocks
- OL1 and OL2: one overload for each winding
- Two-winding (two-speed) motor

## HOW IT WORKS, STEP BY STEP

- 1 Press LOW: L energizes, seals itself and blocks H.
- 2 To go to high speed: STOP, then HIGH.
- 3 H energizes, seals itself and blocks L.
- 4 Each winding has its own overload, set to its own current.

### PRO TIP

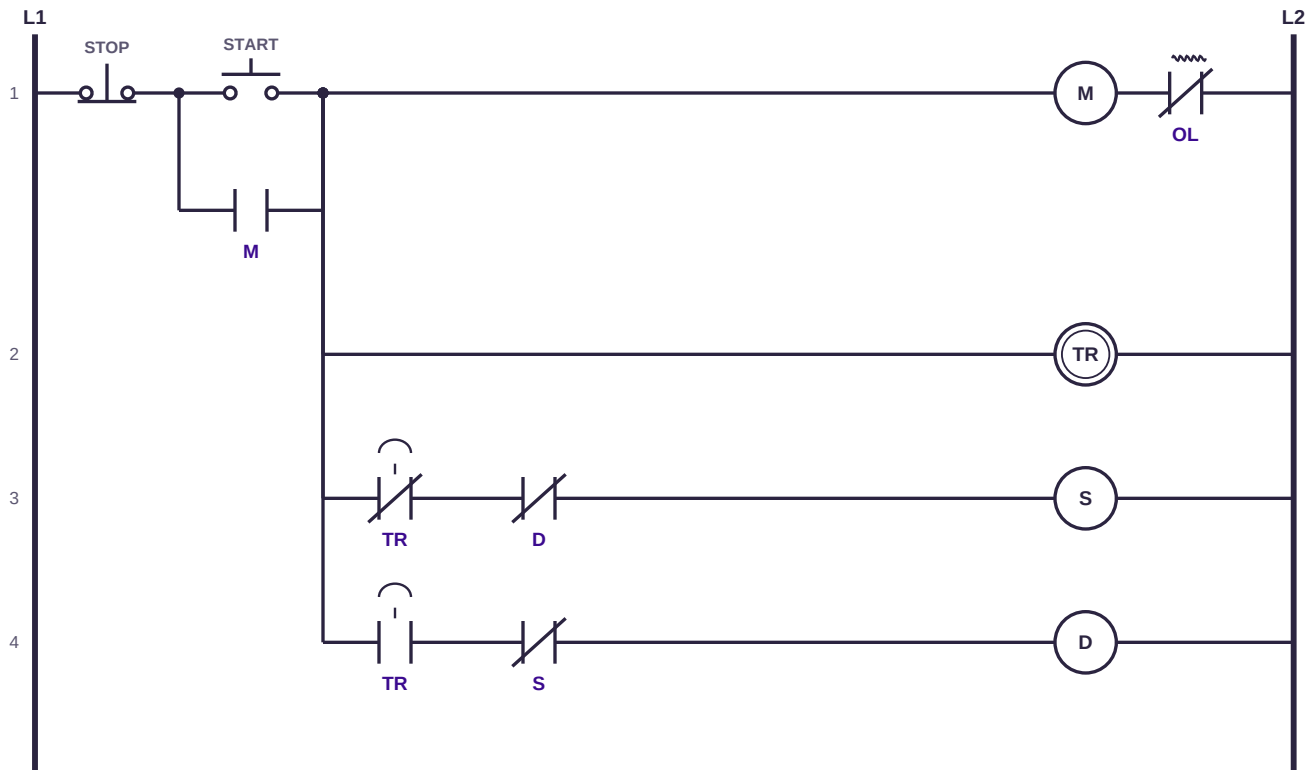
Consequent-pole (Dahlander) motors use a different power wiring with three contactors. Always follow the motor connection diagram.

# Wye-delta (star-delta) starter with timer

## WHAT IT DOES

Starts the motor in wye (lower current) and, after a set time, switches to delta for full power.

### CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- M: main contactor
- S: wye (star) contactor
- D: delta contactor
- TR: on-delay timer (NC timed-open + NO timed-close)
- STOP / START, overload relay

## HOW IT WORKS, STEP BY STEP

- 1 START energizes M and TR; S closes through the TR NC contact: the motor starts in wye.
- 2 When the set time ends, TR opens its NC contact: S drops.
- 3 TR closes its NO contact: D energizes (S NC is closed): the motor runs in delta.
- 4 S and D are interlocked and never close together.

## PRO TIP

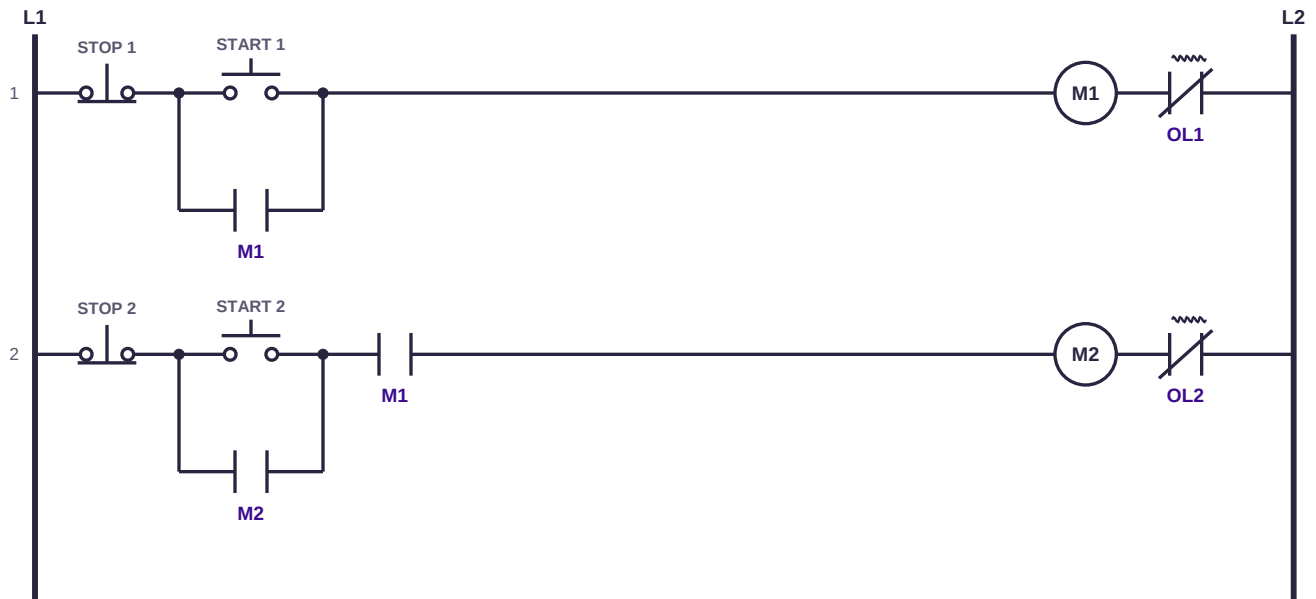
Only motors with 6 leads rated for delta at the line voltage can use wye-delta. Typical transfer time: 5 to 10 seconds.

# Sequential start: motor 2 only after motor 1

## WHAT IT DOES

Motor 2 cannot start unless motor 1 is running, as in conveyors that must not pile up material.

### CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- Two start/stop stations
- M1 and M2 starters
- Extra NO auxiliary contact of M1
- OL1 and OL2

## HOW IT WORKS, STEP BY STEP

- 1 START 2 does nothing while M1 is off.
- 2 Start M1: its NO contact closes in the M2 line.
- 3 Now START 2 starts M2.
- 4 If M1 stops (STOP 1 or OL1), M2 also stops.

## PRO TIP

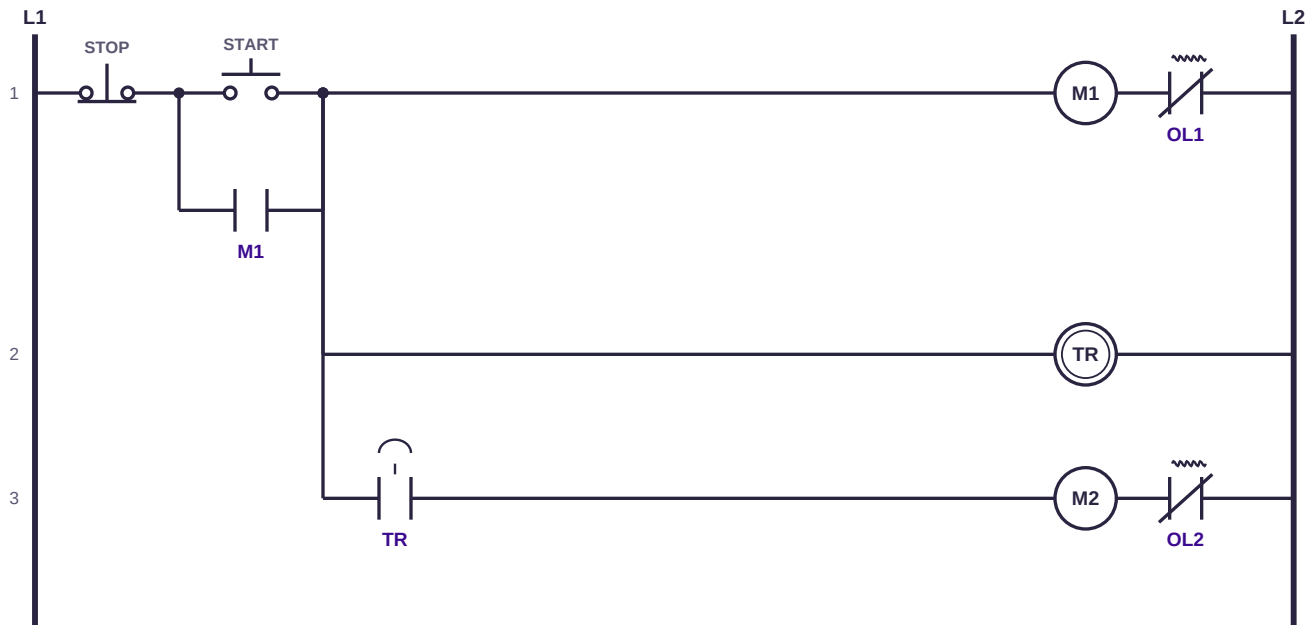
In conveyor lines, the conveyor that receives the material must start first and stop last.

# Automatic timed sequence of two motors

## WHAT IT DOES

One START button: motor 1 starts at once and motor 2 starts automatically after a set delay.

### CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- STOP / START pushbuttons
- M1 and M2 starters
- TR: on-delay timer
- OL1 and OL2

## HOW IT WORKS, STEP BY STEP

- 1 Press START: M1 energizes and seals; TR starts timing.
- 2 When the time is up, the TR contact closes.
- 3 M2 energizes and the second motor starts.
- 4 STOP drops M1, TR and M2 together.

### PRO TIP

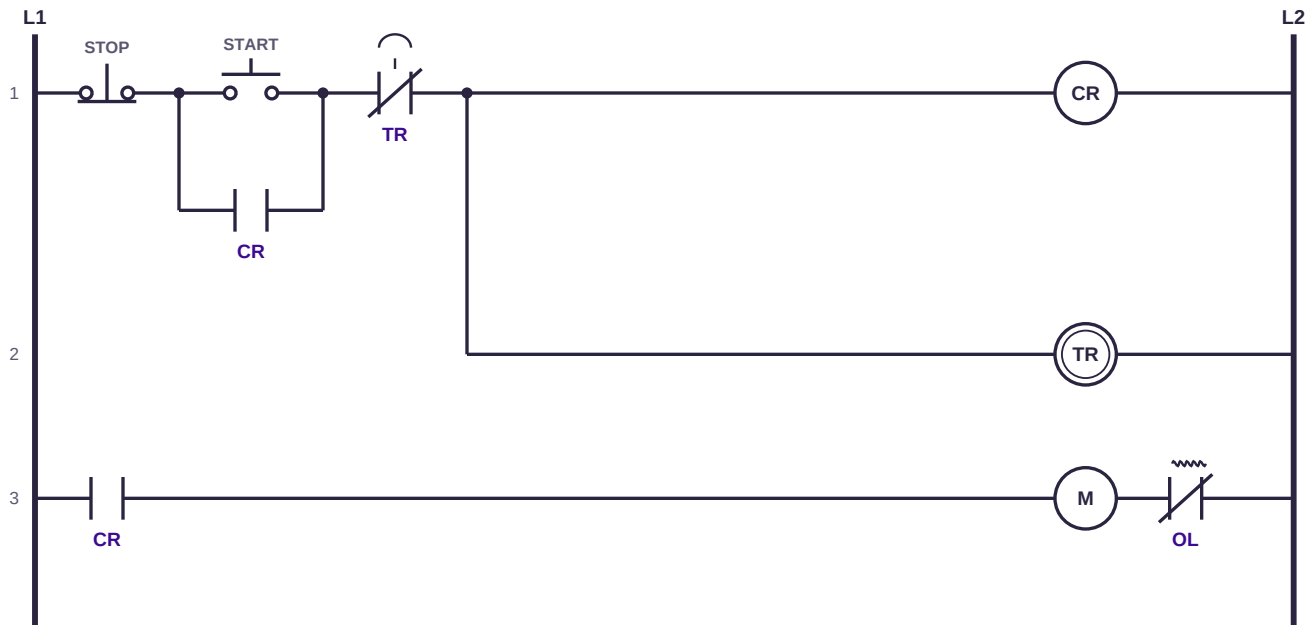
Staggering starts reduces the inrush current on the transformer and avoids voltage dips in the plant.

# Interval timer: run for a set time

## WHAT IT DOES

Press START and the motor runs for an adjustable time, then stops by itself. Good for mixers, pumps and dosing.

### CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- STOP / START pushbuttons
- CR: control relay
- TR: on-delay timer with NC timed-open contact
- M: starter, OL: overload

## HOW IT WORKS, STEP BY STEP

- 1 START energizes CR (sealed) and TR starts timing.
- 2 A CR contact energizes M: the motor runs.
- 3 When the time is up, the TR NC contact opens: CR drops.
- 4 CR drops M and resets TR. The circuit is ready for the next cycle.

## PRO TIP

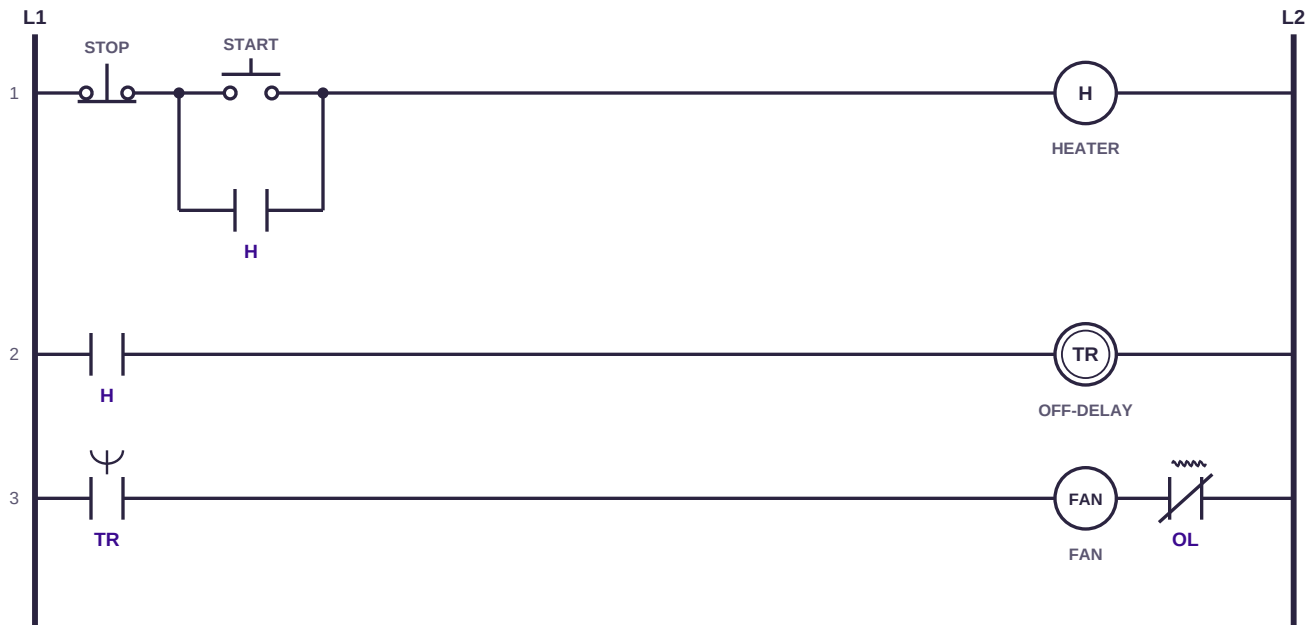
Many plants mark the timer dial with the process name and the time used, so nobody changes it by mistake.

# Off-delay: fan keeps running after the heater stops

## WHAT IT DOES

An off-delay timer keeps a cooling fan on for a few minutes after the heater (or furnace) is turned off.

### CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- H: heater contactor
- TR: OFF-delay timer (NO timed-open contact)
- FAN: fan starter
- STOP / START, overload

## HOW IT WORKS, STEP BY STEP

- 1 START energizes H; the H contact energizes TR.
- 2 The TR contact closes AT ONCE: the fan starts with the heater.
- 3 STOP drops H and TR starts timing.
- 4 When the time is up, the TR contact opens and the fan stops.

## PRO TIP

On-delay times when the coil is ENERGIZED; off-delay times when the coil is DE-ENERGIZED. Check the timer symbol before wiring.

# Flashing light with two timers

## WHAT IT DOES

Two on-delay timers make an oscillator that turns a beacon on and off. Used for alarms and warning lights.

CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- SW: on/off switch
- TR1 and TR2: on-delay timers
- Beacon or pilot light

## HOW IT WORKS, STEP BY STEP

- 1 Close SW: TR1 starts timing (light OFF).
- 2 TR1 closes: the light turns ON and TR2 starts timing.
- 3 TR2 opens its NC contact: TR1 resets, the light goes OFF and TR2 resets.
- 4 TR2 closes again and the cycle repeats.

## PRO TIP

TR1 sets the OFF time and TR2 sets the ON time. Today a single flasher relay does the same job.

# Hand-Off-Auto (HOA) pump control

## WHAT IT DOES

A three-position selector: HAND runs the pump now, OFF keeps it off, AUTO lets a float switch control it.

### CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- SS: 3-position selector HAND / OFF / AUTO
- FS: float switch (or pressure / level switch)
- M: pump starter
- OL: overload

## HOW IT WORKS, STEP BY STEP

- 1 HAND: the HAND contact is closed: the pump runs no matter the level.
- 2 OFF: both contacts open: the pump never runs.
- 3 AUTO: the pump runs only when the float switch closes.
- 4 The overload protects in every position.

### PRO TIP

HAND bypasses the float: a pump left in HAND can run dry. Use it only for tests and maintenance.

# Tank filling with float switch and high-level alarm

## WHAT IT DOES

The pump fills the tank and stops when it is full. A second float turns on an alarm if the level gets too high.

CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- FS1: float switch, opens when the tank is full
- FS2: high-level float switch NO
- M: pump starter, OL: overload
- Alarm light or horn

## HOW IT WORKS, STEP BY STEP

- 1 Low level: FS1 is closed and the pump runs.
- 2 Tank full: FS1 opens and the pump stops.
- 3 When the level drops, FS1 closes again and the pump restarts.
- 4 If FS1 fails and the level keeps rising, FS2 closes and the alarm turns on.

## PRO TIP

Feed the alarm from a separate, protected circuit so it still works if the pump circuit fails.

# Sump pump with high and low floats

## WHAT IT DOES

The pump starts at the high level and keeps running until the low level, so it does not start and stop all the time.

### CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- FSH: high-level float NO (closes at high level)
- FSL: low-level float NO (closed while level is above low)
- M: pump starter with seal-in contact
- OL: overload

## HOW IT WORKS, STEP BY STEP

- 1 The level rises above FSL: FSL closes, but the pump is still off.
- 2 The level reaches FSH: FSH closes and M starts and seals itself.
- 3 The level drops below FSH: M stays on through its seal-in.
- 4 The level reaches FSL: FSL opens and the pump stops.

## PRO TIP

This is the same logic as START/STOP: the high float is the START and the low float is the STOP.

# Duplex pumps with selector (pump 1 / pump 2)

## WHAT IT DOES

One float controls two pumps; a selector chooses which pump works, so you can alternate wear or do maintenance.

### CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- FS: float switch
- SS: selector PUMP 1 / PUMP 2
- M1 and M2: pump starters
- OL1 and OL2

## HOW IT WORKS, STEP BY STEP

- 1 Choose PUMP 1 on the selector.
- 2 When the float closes, only M1 runs.
- 3 Every week (or at each maintenance), switch to PUMP 2.
- 4 The pump not selected can be serviced without stopping the system.

## PRO TIP

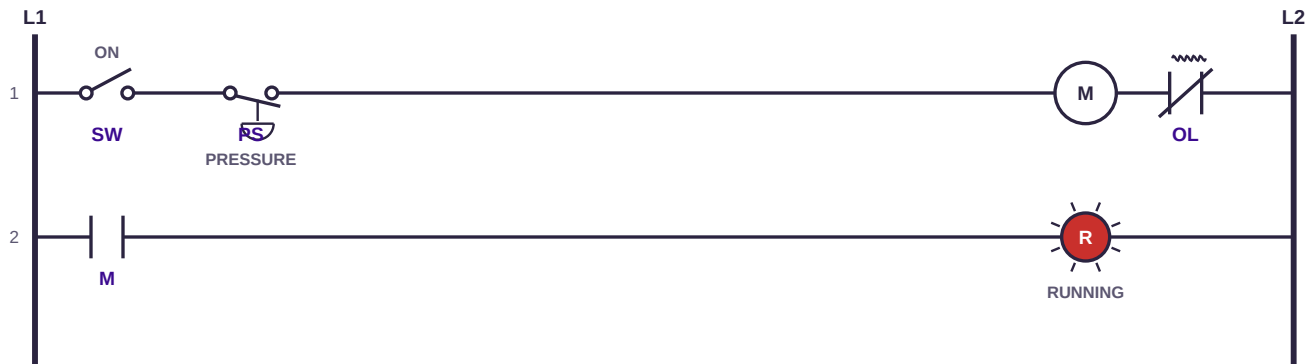
Automatic alternation is done with an alternating relay: it changes the pump at every cycle without anyone touching the selector.

# Air compressor with pressure switch

## WHAT IT DOES

The pressure switch starts the compressor at low pressure (cut-in) and stops it at high pressure (cut-out).

### CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- SW: on/off switch
- PS: pressure switch NC (opens at cut-out)
- M: compressor starter, OL: overload
- Pilot light

## HOW IT WORKS, STEP BY STEP

- 1 Low pressure: PS is closed and the compressor runs.
- 2 Pressure reaches the cut-out value: PS opens and M stops.
- 3 Air is used and pressure drops to the cut-in value: PS closes again.
- 4 The pilot light shows when the compressor is running.

## PRO TIP

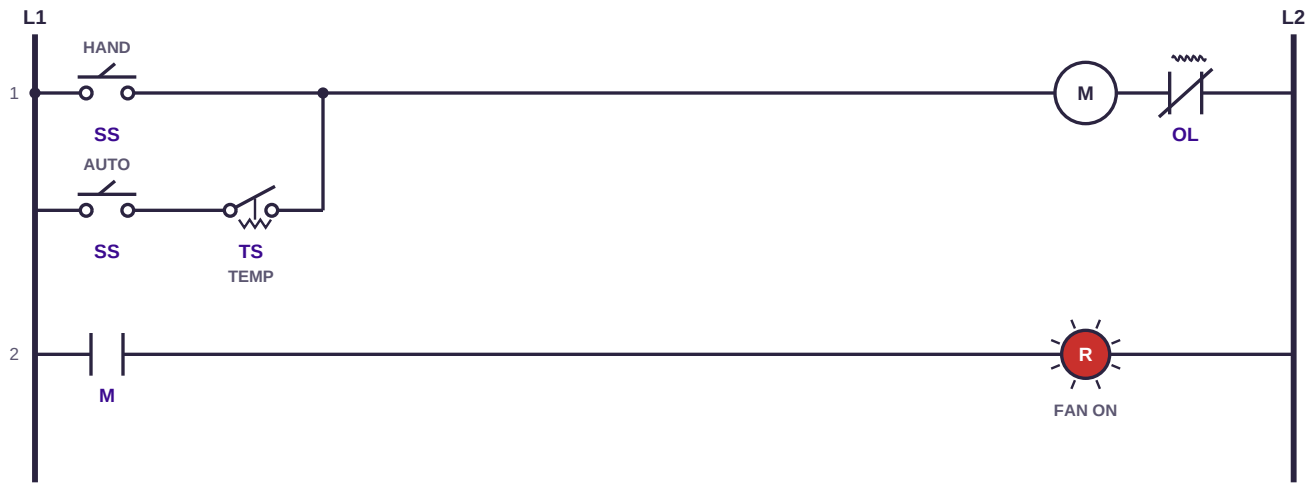
The difference between cut-in and cut-out (differential) sets how often the compressor starts. Too small = too many starts.

# Exhaust fan controlled by thermostat

## WHAT IT DOES

A thermostat starts the fan when the room gets hot and stops it when it cools down.

### CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- TS: thermostat NO (closes on rising temperature)
- SS: HAND / OFF / AUTO selector
- M: fan starter, OL: overload
- Pilot light

## HOW IT WORKS, STEP BY STEP

- 1 AUTO: when the temperature passes the set point, TS closes.
- 2 M energizes and the fan runs; the light turns on.
- 3 When the room cools down, TS opens and the fan stops.
- 4 HAND runs the fan at any temperature.

## PRO TIP

For heating, use a thermostat that closes on FALLING temperature. Check which type you have before wiring.

# Lighting contactor with photocell (HOA)

## WHAT IT DOES

Outdoor lights turn on by themselves at dusk and off at dawn, with a selector for manual testing.

### CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- PC: photocell (closes in the dark)
- SS: HAND / OFF / AUTO selector
- LC: lighting contactor
- Branch circuit breakers for the lights

## HOW IT WORKS, STEP BY STEP

- 1 AUTO: at dusk the photocell closes and LC turns the lights on.
- 2 At dawn the photocell opens and the lights turn off.
- 3 HAND turns the lights on to test them during the day.
- 4 OFF keeps the lights off (maintenance).

## PRO TIP

Point the photocell north (in the northern hemisphere) and away from the lights it controls, or it will turn them on and off in a loop.

# Time clock lighting with override button

## WHAT IT DOES

A time clock turns the lights on and off on a schedule; a timed override button turns them on outside the schedule.

### CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- TC: time clock contact
- OVERRIDE: pushbutton NO
- CR: control relay, TR: on-delay timer
- LC: lighting contactor

## HOW IT WORKS, STEP BY STEP

- 1 During the schedule, TC is closed and LC keeps the lights on.
- 2 Outside the schedule, press OVERRIDE: CR energizes and seals.
- 3 CR turns LC on and starts TR (for example, 2 hours).
- 4 When TR times out, its NC contact opens: CR drops and the lights go off.

## PRO TIP

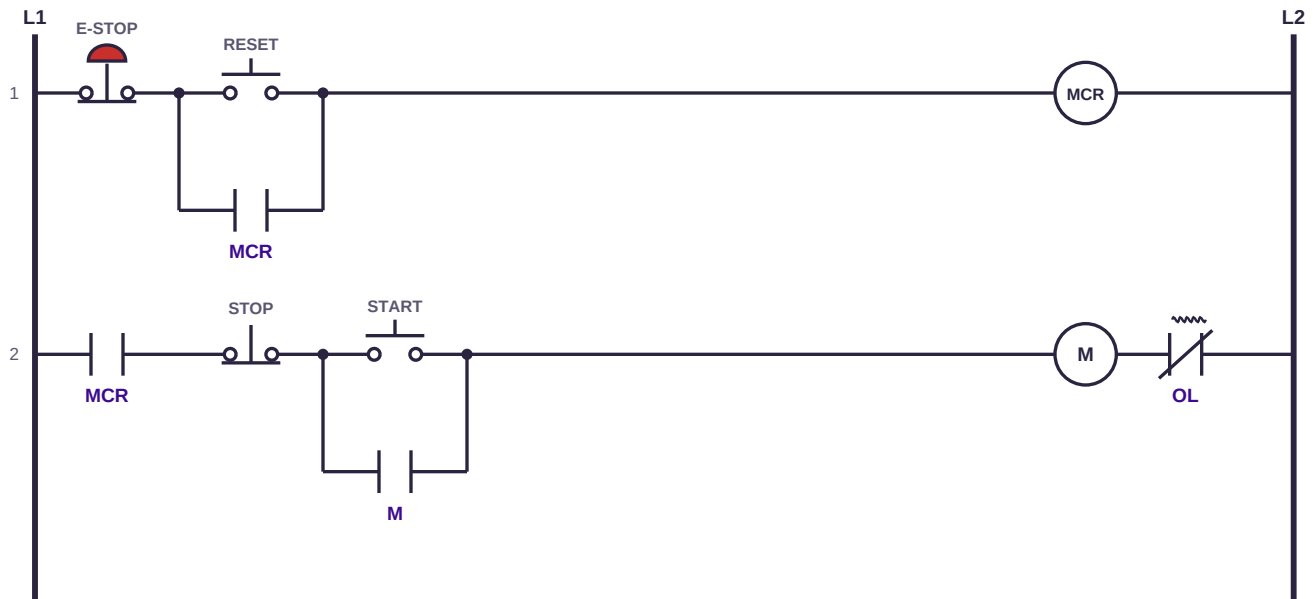
Time clocks with battery backup keep the schedule during power outages. Check the battery once a year.

# Emergency stop with master control relay (MCR)

## WHAT IT DOES

A mushroom-head E-STOP drops a master relay that removes power from all the control circuits of the machine.

### CONTROL CIRCUIT (LADDER DIAGRAM)



## COMPONENTS

- E-STOP: mushroom-head pushbutton NC, latching (twist or pull to release)
- RESET: pushbutton NO
- MCR: master control relay
- Machine circuits (here: one start/stop)

## HOW IT WORKS, STEP BY STEP

- 1 Release the E-STOP and press RESET: MCR energizes and seals.
- 2 MCR contacts give power to the machine circuits: START now works.
- 3 Press E-STOP: MCR drops and every circuit loses power at once.
- 4 The machine stays off until the E-STOP is released AND RESET is pressed again.

## PRO TIP

An E-STOP must always be NC and wired directly, never through a PLC input alone. Modern machines use a safety relay rated for the risk level.

# Keep practicing

- 1 Draw each diagram on paper from memory, then compare.
- 2 Mount the circuits on a training board with 24 V control before working with real voltage.
- 3 Before energizing: check wiring against the diagram, tighten terminals and test the coil voltage.
- 4 Keep the diagram inside the panel door and update it after every change.

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