



The Printer Working Group

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PWG Safe G-Code Subset for 3D Printing v1.0

Status: Approved

Abstract: This Best Practice document defines a "safe" subset of G-code for use in 3D printing with IPP along with the capabilities and parameters needed to allow a client to generate G-code compatible with the printer.

This is a PWG Best Practice. For a definition of a "PWG Best Practice", see:

<https://ftp.pwg.org/pub/pwg/general/pwg-process30.pdf>

This Best Practice is available electronically at:

<https://ftp.pwg.org/pub/pwg/informational/bp-pwgsafegcode10-20190604-5199.7.docx>
<https://ftp.pwg.org/pub/pwg/informational/bp-pwgsafegcode10-20190604-5199.7.pdf>

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Title: *PWG Safe G-Code Subset for 3D Printing v1.0*

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Table of Contents

| | |
|--|----|
| 1. Introduction..... | 4 |
| 2. Terminology..... | 5 |
| 2.1 Conformance Terminology..... | 5 |
| 2.2 Protocol Role Terminology..... | 5 |
| 2.3 Other Terminology..... | 5 |
| 2.4 Acronyms and Organizations..... | 5 |
| 3. PWG Safe G-Code Subset..... | 6 |
| 3.1 G0 and G1: (Rapid/Controlled) Linear Move..... | 6 |
| 3.2 G4: Dwell..... | 7 |
| 3.3 G21: Set Units to Millimeters..... | 7 |
| 3.4 G28: Move to Origin (Home)..... | 7 |
| 3.5 G90: Set Absolute Positioning..... | 7 |
| 3.6 G91: Set Relative Positioning..... | 7 |
| 3.7 G92: Set Position..... | 7 |
| 3.8 M82: Set Absolute Extrusion..... | 8 |
| 3.9 M83: Set Relative Extrusion..... | 8 |
| 3.10 Tnnn: Set Tool..... | 8 |
| 4. Generating Safe G-Code..... | 9 |
| 4.1 Material Extrusion Parameters..... | 9 |
| 4.2 Support for Additional "Safe" G-Code Commands..... | 9 |
| 5. Printing Safe G-Code..... | 10 |
| 5.1 Adding Printer-Specific Machine Commands..... | 10 |
| 5.2 Printer-Specific Attributes and Values..... | 10 |
| 5.3 Canceling Jobs..... | 11 |
| 6. IANA Considerations..... | 12 |
| 6.1 Attribute Registrations..... | 12 |
| 6.2 MIME Media Type Registration..... | 12 |
| 7. References..... | 14 |
| 8. Author's Address..... | 16 |

List of Tables

| | |
|---|----|
| Table 1 - Information Needed to Generate Safe G-Code..... | 9 |
| Table 2 - IPP Job Template Attributes..... | 10 |

1. Introduction

G-Code [ISO6893-1] [RS274D] [RS274NGC] [REPRAP] is a commonly-used format for 3D printing with so-called Fused Deposition Modeling (FDM) printers. Besides the commands used to move the print head and/or platform and to extrude material, G-Code includes a variety of device control (e.g., set extruder temperature) and hardware access (e.g., write file to SD card) commands that pose serious safety and security concerns. To make matters worse, such commands are often printer-specific or have printer-specific variations in syntax, requiring the equivalent of printer driver software to produce G-Code suitable for a particular model or firmware version. Finally, differences in filament and extruder nozzle diameters mean that G-Code created for one print job may not work on the same printer due to changes to the material or extruder.

The IPP 3D Printing Extensions v1.1 [PWG5100.21] define the model and semantics for networked 3D printing, along with a required high-level 3D file format. However, the processing requirements of such a format require either improved printer controllers with greater memory, storage, and CPU capacity or the use of Cloud services to offload that processing.

The IPP Shared Infrastructure Extensions (INFRA) [PWG5100.18] specification defines the model and semantics for Cloud printing, however it does not specify an intermediate format suitable for 3D printing.

This document defines a "safe" subset of G-Code that can be used for direct and Cloud printing configurations, along with a description of the capabilities and parameters that will be needed to generate suitable layers for printing to the target printer.

The goal of this document is to enable the use of IPP with existing entry-level FDM printers that are not able to perform their own slicing and to enable generic Cloud and local infrastructure services to provide slicing services to existing FDM printers. Support for other kinds of 3D printers will likely require an intermediate format such as the 3MF Slice Extension [3MF-SLICE].

2. Terminology

2.1 Conformance Terminology

Capitalized terms, such as MUST, MUST NOT, RECOMMENDED, REQUIRED, SHOULD, SHOULD NOT, MAY, and OPTIONAL, have special meaning relating to conformance as defined in Key words for use in RFCs to Indicate Requirement Levels [BCP14]. The term CONDITIONALLY REQUIRED is additionally defined for a conformance requirement that applies when a specified condition is true.

2.2 Protocol Role Terminology

The following protocol roles are defined to specify unambiguous conformance requirements:

Client: Initiator of outgoing connections and sender of outgoing operation requests (Hypertext Transfer Protocol -- HTTP/1.1 [RFC7230] User Agent).

Printer: Listener for incoming connections and receiver of incoming operation requests (Hypertext Transfer Protocol -- HTTP/1.1 [RFC7230] Server) that represents one or more Physical Devices or a Logical Device.

2.3 Other Terminology

Cloud: the environment supporting services such as Cloud Computing.

Cloud Computing: "... a model for enabling ubiquitous, convenient, on demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction." The NIST Definition of Cloud Computing [NISTSP800-145].

Fused Deposition Modeling: A 3D printing process that extrudes a molten material to draw layers, sometimes also called material extrusion.

2.4 Acronyms and Organizations

IANA: Internet Assigned Numbers Authority, <https://www.iana.org/>

IETF: Internet Engineering Task Force, <https://www.ietf.org/>

ISO: International Organization for Standardization, <https://www.iso.org/>

PWG: Printer Working Group, <https://www.pwg.org/>

3. PWG Safe G-Code Subset

This document defines a safe G-Code subset with the MIME Media Type "application/vnd.pwg-safe-gcode". Safe G-Code files consist solely of the following commands which represent the common subset of commands supported by most FDM printers:

- G0: Rapid Linear Move
- G1: Controlled Linear Move
- G4: Dwell
- G21: Set Units to Millimeters
- G28: Move to Origin (Home)
- G90: Set Absolute Positioning
- G91: Set Relative Positioning
- G92: Set Position
- M82: Set Absolute Extrusion
- M83: Set Relative Extrusion
- Tnnn: Set Tool

Most machine ("M") commands are not allowed since they directly control or access the machine hardware. Temperature control and other machine settings are the responsibility of the IPP Printer, which will likely use the IPP Job Template attribute values to send the corresponding printer-specific G-code commands to a lower-level controller.

The line number command ("N") and checksum ("*") are similarly not allowed because they are used for direct communications with the controller - IPP provides the necessary infrastructure for reliable communication of the G-Code file to the IPP Printer.

Comments starting with the ";" character are allowed and continue to the end of the current line.

For simplicity, safe G-Code always uses millimeters for the units (the default).

3.1 G0 and G1: (Rapid/Controlled) Linear Move

These commands move the current tool (extruder) and/or extrude material for printing. Parameters are:

Xnnn: Set X position in millimeters

Ynnn: Set Y position in millimeters

Znnn: Set Z position in millimeters

Ennn: Extrude the specified number of millimeters of material

Fnnn: Set the feed rate in millimeters/minute

Note: The "S" parameter is not allowed in safe G-Code.

3.2 G4: Dwell

This command pauses printing for a specifies amount of time. The "Pnnn" parameter specifies the time interval in milliseconds.

3.3 G21: Set Units to Millimeters

This command explicitly specifies that coordinates are in millimeters (the default).

Note: This command is only provided for completeness - there is no support in safe G-Code for any other units.

3.4 G28: Move to Origin (Home)

This command moves the current tool to the home position (end stops). The "X", "Y", and "Z" parameters may optionally be specified to move the tool on the specified axes - if not supplied the tool is moved on all axes.

3.5 G90: Set Absolute Positioning

This command specifies that all coordinates are relative to the origin of the machine.

3.6 G91: Set Relative Positioning

This command specifies that all coordinates are relative to the current position of the tool.

3.7 G92: Set Position

This command sets the current tool positions without moving or extruding material. Parameters for this command are:

Xnnn: Set X position in millimeters

Ynnn: Set Y position in millimeters

Znnn: Set Z position in millimeters

Ennn: Set extrusion to the specified number of millimeters of material

All positions are set to 0 if no parameters are specified.

3.8 M82: Set Absolute Extrusion

This command specifies that the extrusion ("E") coordinates in move commands are absolute.

3.9 M83: Set Relative Extrusion

This command specifies that the extrusion ("E") coordinates in move commands are relative.

3.10 Tnnn: Set Tool

This command sets the current tool (extruder) to use, starting at 0. Tool numbers correspond to the index within the "materials-col" Job Template attribute.

4. Generating Safe G-Code

IPP Clients [STD92] and Infrastructure Printers [PWG5100.18] can generate safe G-Code using the values of Printer Description attributes reported by the IPP Printer or Proxy. Table 1 shows the information that is needed to generate safe G-Code for a FDM printer. The "materials-col" values are obtained from the "materials-col-database" and/or "materials-col-ready" Printer Description attributes which provide a list of all possible materials and those that are loaded in the Printer, respectively.

Table 1 - Information Needed to Generate Safe G-Code

| Description | Current IPP Attribute |
|---|---|
| Accuracy limits/minimum layer height | print-accuracy-supported (collection) |
| Build platform dimensions | printer-volume-supported (collection) |
| Build platform shape | platform-shape (type2 keyword) |
| Extruder nozzle size/maximum layer height | See section 4.1 |
| Filament diameter | materials-col.material-diameter (integer) |
| Retraction support | See section 4.1 |

4.1 Material Extrusion Parameters

IPP 3D v1.1 [PWG5100.21] defines the following "materials-col" member attributes for the extruder nozzle size and whether retraction is used:

"material-nozzle-diameter (integer(0:MAX))": Specifies the required extruder diameter in nanometers, with the value 0 indicating the nozzle diameter is less than 1 nanometer.

"material-retraction (boolean)": Specifies whether retraction is used with the material.

A corresponding "material-nozzle-diameter-supported (1setOf (integer(0:MAX) | rangeOfInteger(0:MAX)))" Printer Description attribute provides the supported nozzle diameter values. The presence of 'material-retraction' in the "materials-col-supported" Printer Description attribute indicates that the Printer supports material retraction.

4.2 Support for Additional "Safe" G-Code Commands

In addition to the common subset of G-Code commands listed in the previous sections, newer FDM printers support additional "safe" commands such as mixing of extruded material ("M163", "M164", and "M165"), controlled arc ("G2" and "G3") and Bézier cubic spline ("G5"). In order for a generic slicer to support these commands, a FDM printer needs to advertise its support for them. The usual method employed for IPP is a PDL-specific capability attribute, such as "pwg-safe-gcode-supported (1setOf text(MAX))" with each value corresponding to a named command.

5. Printing Safe G-Code

Printers that support safe G-Code can largely pass the print file to the controller - typically all that is required is to add device-specific commands to set temperatures and other machine settings, send the print file, and then add device-specific commands to return it to an idle state.

Status information returned by the device can be used to set the values of the various IPP Printer Status attributes.

5.1 Adding Printer-Specific Machine Commands

IPP Job Template attributes provide the values for extruder and build platform temperatures, as well as the list of materials used in the print job. Table 2 lists the standard attributes a FDM printer can use to configure the device prior to printing.

Table 2 - IPP Job Template Attributes

| Description | IPP Attribute(s) | Typical G-Code |
|----------------------------|--|-------------------------|
| Build platform temperature | platform-temperature | M140/M190 |
| Chamber humidity | printer-volume-humidity | M146 |
| Chamber temperature | printer-volume-temperature | M141/M191 |
| Extruder nozzle size | materials-col/material-nozzle-diameter | |
| Extruder temperature | materials-col/material-temperature | M104/M109 |
| Filament color | materials-col/material-color | |
| Filament diameter | materials-col/material-diameter materials-col/material-diameter-tolerance | M200 |
| Filament type | materials-col/material-type | |
| Flow rate | materials-col/material-rate materials-col/material-rate-units | M203 |
| Job Name | job-name | M531 |
| Print accuracy | print-accuracy | M201/M202/ M222/M223 |
| Print quality/speed | print-quality | |

When an IPP Client does not specify one or more of these attributes, the corresponding default attribute values are used - "materials-col-default", "platform-temperature-default", "print-accuracy-default", "print-quality-default", "printer-volume-humidity-default", and "printer-volume-temperature-default" for the attributes in Table 2.

5.2 Printer-Specific Attributes and Values

IPP allows implementors to add Printer-specific attributes and values as defined in section 7 of [STD92]. However, Printers cannot depend on IPP Clients or Infrastructure Printers to support such attributes or values, particularly for generation of safe G-Code. Default values SHOULD be used as a backup when necessary.

5.3 Canceling Jobs

When a Job is canceled, Printers SHOULD stop sending G-Code commands as soon as possible and then send device-specific commands to the controller to return the Printer to an idle state.

6. IANA Considerations

6.1 Attribute Registrations

The attribute defined in this document will be published by IANA according to the procedures in IPP/1.1 Model and Semantics [STD92] section 7.2 in the following file:

<https://www.iana.org/assignments/ipp-registrations>

The registry entries will contain the following information:

| Printer Description attributes: | Reference |
|---|-------------|
| ----- | ----- |
| pwg-safe-gcode-supported (1setOf text(MAX)) | [SAFEGCODE] |

6.2 MIME Media Type Registration

The MIME media type defined in this document will be published by IANA according to the procedures in the Media Type Specifications and Registration Procedures [BCP13] in the following file:

<https://www.iana.org/assignments/media-types>

The registry will contain the following information:

Type name: application

Subtype name: vnd.pwg-safe-gcode

Required parameters: N/A

Optional parameters: N/A

Encoding considerations: US ASCII

Security considerations: Safe G-code prohibits machine control commands, however it is up to the consumer to verify that such commands are not part of the print file.

Interoperability considerations: While the format is interoperable, the contents of each file are still specific to the combination of material parameters and printer capabilities used for the G-code.

Published specification: <https://ftp.pwg.org/pub/pwg/informational/bp-pwgsafegcode10-20190604.pdf>

Applications that use this media type: IPP 3D

Fragment identifier considerations: N/A

Additional information:

Deprecated alias names for this type: N/A
Magic number(s): N/A
File extension(s): pwggc
Macintosh file type code(s): N/A

Person & email address to contact for further information: Michael Sweet,
msweet@apple.com

Intended usage: COMMON

Restrictions on usage: N/A

Author/Change controller: The Printer Working Group, c/o The IEEE Industry
Standards and Technology Organization, 445 Hoes Lane, Piscataway, NJ
08854, USA

Provisional registration? (standards tree only): No

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[STD92]

M. Sweet, I. McDonald, "Internet Printing Protocol/1.1", STD 92 / RFC 8011, January 2017, <https://tools.ietf.org/html/std92>

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